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GEOLOGY AND MINERAL RESOURCES OF THE HARRISBURG WEST AREA, CUMBERLAND AND YORK COUNTIES, PENNSYLVANIA

Samuel I. Root

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
BUREAU OF
TOPOGRAPHIC AND GEOLOGIC SURVEY
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by Samuel I. Root
Pennsylvania Geological Survey

PENNSYLVANIA GEOLOGICAL SURVEY

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PREFACE

This report is part of a program of the Bureau of Topographic and Geologic Survey to describe the details of bedrock and surficial materials of the Cumberland Valley, and determine their economic potential, environmental and engineering properties, and hydrologic character. The report and accompanying map fill in an area between previously mapped portions of Dauphin and Franklin Counties.

The area of this report lies along the west bank of the Susquehanna River in Cumberland County and as such is part of the rapidly expanding metropolitan Harrisburg area. It is part of the major historic transportation and industrial development corridor that extends along the Great Valley from Easton to Chambersburg. If it is to expand in an optimum manner, such a dynamic area requires definitive data on mineral and water resources and information on the environmental and engineering properties of the rocks. This report deals principally with distribution of the rocks and their economic potential. Two related reports, utilizing the bedrock data of this report, treat separately the hydrology of the Cumberland Valley (Becher and others, in preparation) and the environmental geology of the greater Harrisburg area (McGlade and Geyer, 1976).

Information on economic resources and distribution of the rock strata will be of use to land use planners, property owners, and the extractive-mineral industry. Summary statements of the environmental and engineering rock properties are of interest to those engaged in land use evaluation, engineering, and construction. Detailed rock descriptions and the geologic map should assist geologists and engineers engaged in site-specific projects.

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(in envelope)

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GEOLOGY AND MINERAL RESOURCES OF THE HARRISBURG WEST AREA, CUMBERLAND AND YORK COUNTIES, PENNSYLVANIA

by
Samuel I. Root

ABSTRACT

This report describes the geology and mineral resources of slightly more than 100 square miles (259 km^2) of the Harrisburg West Shore area in Cumberland County. Included in the area are rocks of the Great Valley and Triassic Basin.

Two sequences of carbonate* and argillaceous* rocks occur in the Great Valley. The Cumberland Valley sequence includes rocks ranging from Upper Cambrian to Upper Ordovician age. From oldest to youngest these are the Conococheague Group, Beekmantown Group, St. Paul Group, and Chambersburg Formation, which comprise a conformable succession of shallow-water marine carbonate rocks several thousand feet thick. Conformably overlying these rocks is the Middle and Upper Ordovician Martinsburg Formation distal-turbidite* sequence with allochthonous* graywackes*, calcareous sandstones and conglomerates, limestones, and maroon mudstones. Thrust over these rocks is a sequence of rocks characteristic of the Lebanon Valley; this sequence includes slices of limestone of the Lower Ordovician Epler Formation and Middle Ordovician Myerstown Formation and shale of the Martinsburg Formation. Bedding is virtually all reoriented into the pervasive cleavage of this sequence.

Truncating these rocks on the south is the Triassic red-bed sequence of nonmarine, shallow-water mudstones and siltstones with subordinate amounts of sandstone and conglomerate. The sediments are extensively intruded by diabase*, both as saucer-like sheets and as dikes. Most of the diabase is a quartz normative tholeiite* (York Haven type) consisting of 1.1 percent TiO_2 in chilled margins. A second type of quartz normative tholeiite (Rossville) with 0.7 percent TiO_2 forms two dikes in the mapped area.

Surficial deposits of high and low terrace gravels and Quaternary alluvium occur adjacent to major streams. Colluvium* occurs along the slope and foot of Blue Mountain.

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*To assist the reader, words followed by an asterisk are defined in the glossary beginning on p. 80.

Rocks of the Cumberland Valley sequence are part of the South Mountain anticlinorium, which is autochthonous* and characterized by gently eastward plunging asymmetrical folds with northward vergence*. Several large thrusts, dipping south at 60° and generally parallel to the fold, truncate the folds. An extensive cleavage (S_2) developed at the time of folding and faulting, and all are considered to represent an early Alleghanian deformational event (D_2). Some of the Martinsburg allochthonous lithologic units show a folding and cleavage indicative of an earlier deformation (Taconic, D_1).

Emplaced upon the South Mountain anticlinorium, on a very low angle fault, is the Yellow Breeches thrust plate, which is composed of rock slices of the Lebanon Valley sequence that are part of the inverted limb of a regional nappe. Development of the nappe and associated principal cleavage is postulated as a Taconic event (D_1). However, Yellow Breeches thrusting (D_3) is much younger than nappe development (D_1) and only slightly younger than the South Mountain deformation (D_2). It is considered a late Alleghanian event. Associated with Yellow Breeches thrusting is local reorientation of the earlier structural fabrics*.

The southern part of the mapped area is occupied by rocks of the Triassic Basin, which define two bedding domains*. Bedding in the more extensive western domain dips approximately 40° north and in the smaller eastern domain dips approximately 25° west. A fault or hinge line separates the two domains and probably links with a Triassic age normal fault on the Yellow Breeches plate. Traditionally the north margin of the Triassic Basin has been considered as a large normal fault, although in the mapped area there was no direct evidence observed that confirms a fault at the margin. It appears that locally at the north margin the Paleozoic surface slopes gently south beneath southward-dipping Triassic beds. However, it is inferred that within a few hundred feet of the Triassic contact there must be a major southeast-dipping normal fault that downdrops the Triassic rocks on the southeast, tilting them to the northwest. It is further inferred that there are other strike-parallel antithetic* faults within the Triassic Basin. Regional relationships and geophysical studies indicate that the deepest part of the Triassic Basin is not at the north margin but in the middle of the present Gettysburg Basin. Large amounts of diabase have invaded these rocks and locally baked them, resulting in erosionally resistant ridges and hills.

Evaluation of the mineral economic potential of the area indicates some of the shales have a potential as brick and tile products, structural clay products, and lightweight aggregate. Several of the limestone formations may be used as a source of Type A coarse aggregate, lime for Portland cement, and agricultural limestone. The lower and upper portions of the St. Paul Group limestones are of the valuable high-calcium type. Analyses and test results from these formations are presented in the text. The diabase is an extremely good quality Type A coarse aggregate. Sand and gravel may be extracted as a source of fine aggregate and locally even coarse aggregate.

INTRODUCTION

The rocks of eastern Cumberland and northern York Counties, including all of the Lemoyne and most of the Steelton and Harrisburg West 7½-minute quadrangles, were studied in this project (Figure 1).

PREVIOUS WORK

The most recent prior geologic mapping in this area is that of Stose and Jonas (1939). Nominally that report included only York County; however, a portion of Cumberland County was presented on their geologic map. Although considerable discrepancy occurs between their mapping of the Cambro-Ordovician rocks and the mapping in this report, their report is of considerable value and reflects adherence to high standards. Work previous to theirs generally does not furnish the detail necessary for present geologic application.

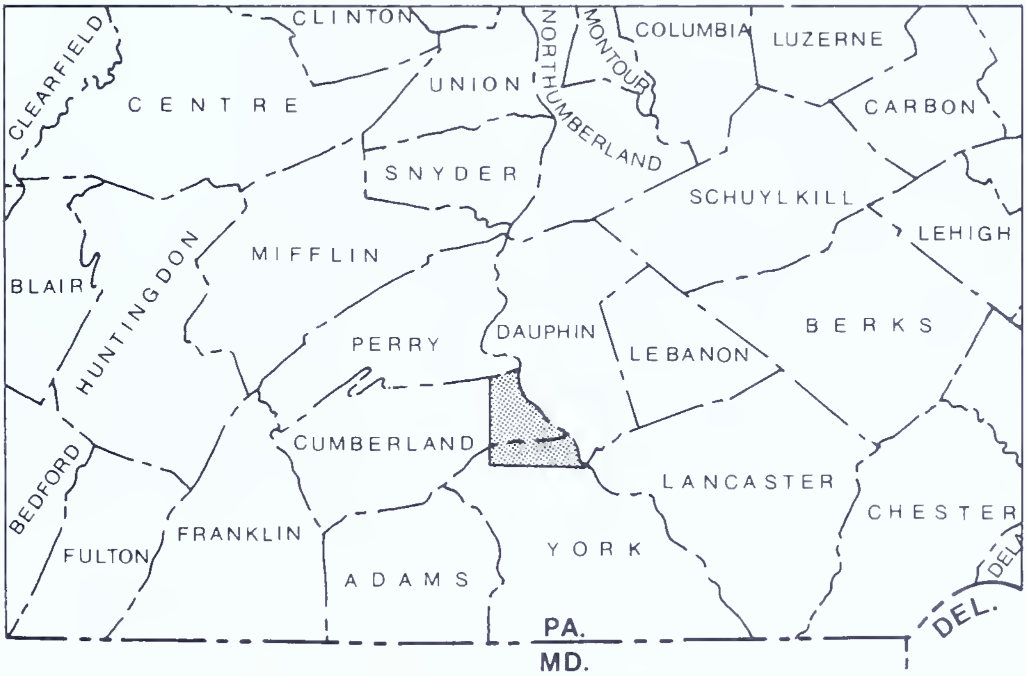


Figure 1. Index map of mapped area.

ACKNOWLEDGEMENTS

S. I. Root mapped all rocks except the diabase dikes, which were mapped by R. C. Smith, II. Diabase analyses, petrography, and geochemical studies were done as part of Smith's (1973) thesis research at the Pennsylvania State University. All other laboratory studies were done under the auspices of the Pennsylvania Geological Survey. The authors gratefully acknowledge the assistance of D. B. MacLachlan, who greatly aided in preparation and review of this report. Dr. A. G. Harris, of the U. S. Geological Survey, kindly identified the conodonts from this area. The authors are grateful to colleagues A. A. Socolow, D. M. Hoskins, R. T. Faill, and A. R. Geyer for discussions and manuscript review that aided in geologic interpretation and subsequent presentation. Information on water wells was kindly supplied by A. Becher of the U. S. Geological Survey. Acknowledgements are extended informally to other individuals, too numerous to mention, in all sectors who aided in the preparation of this report in diverse ways.

STRATIGRAPHY

INTRODUCTION

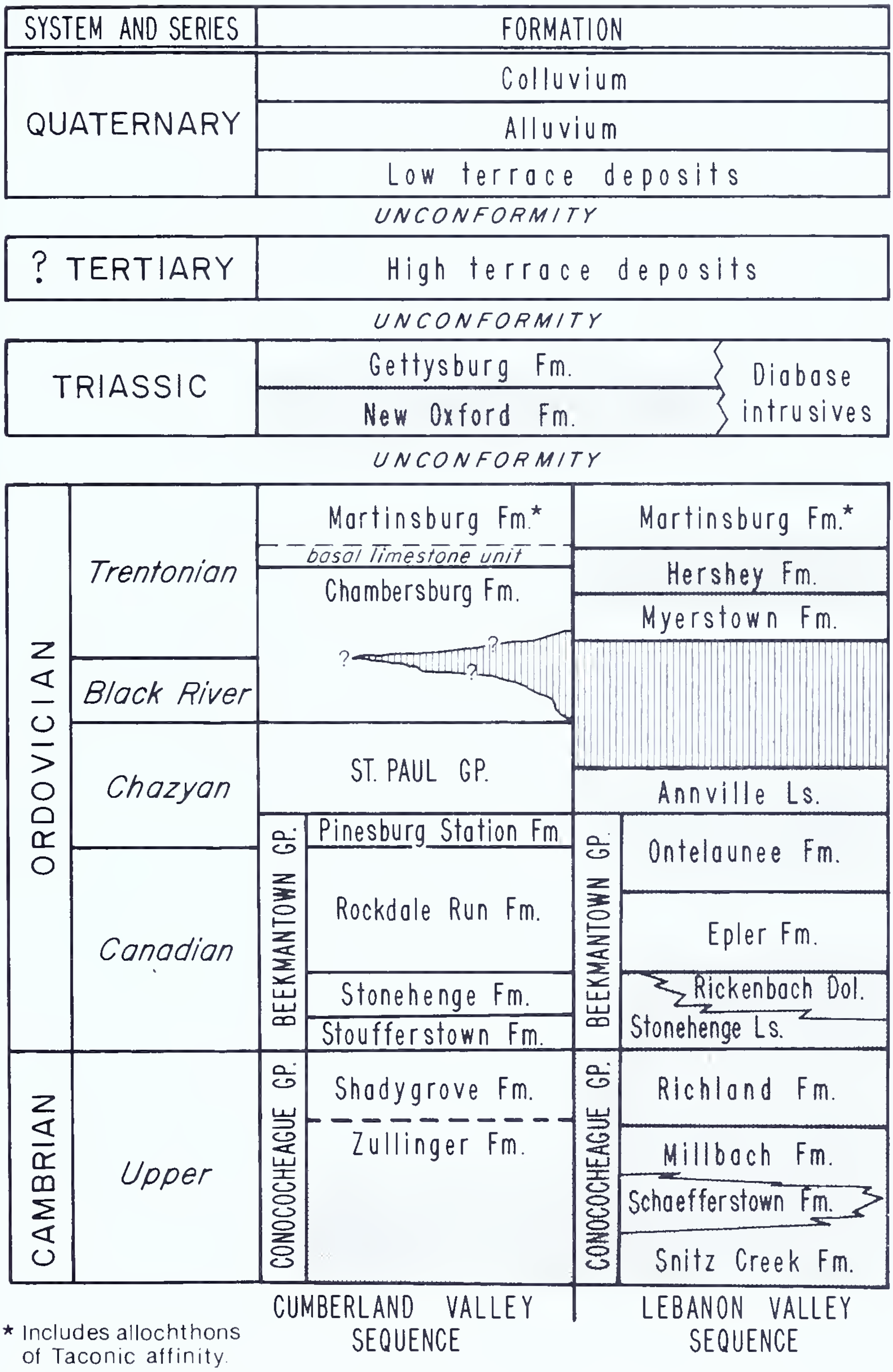
Rocks mapped in the Harrisburg West area include Cambro-Ordovician carbonate rocks and Ordovician shales on the north, and Triassic red beds and diabase sheets and dikes on the south. Tertiary and Quaternary surficial deposits are present as limited deposits along major streams, terraces, and on the lower slopes of larger mountains.

Cambro-Ordovician rocks do not comprise a single stratigraphic section because terminal Paleozoic (late Alleghanian) faulting has juxtaposed rocks that were originally deposited in widely separated parts of the Appalachian Basin. Thus, two sets of stratigraphic nomenclature are established for these rocks—north of the Yellow Breeches thrust the rocks are referred to as the Cumberland Valley stratigraphic sequence and south of the thrust the rocks are part of the Lebanon Valley stratigraphic sequence (Plate 1). Stratigraphic differences between correlative units across the Yellow Breeches thrust are large with respect to lithofacies variation within either sequence (Figure 2). These relationships have been described in detail by MacLachlan and Root (1966) and MacLachlan (1967).

CUMBERLAND VALLEY SEQUENCE

Elbrook Formation

On the basis of mapping in the Mechanicsburg quadrangle on the west, limestones of the Elbrook Formation are believed to occur in a tiny part of the mapped area. There are no outcrops to confirm this. Because of



SYSTEM AND SERIES	FORMATION	
QUATERNARY	Colluvium	
	Alluvium	
	Low terrace deposits	

UNCONFORMITY

? TERTIARY	High terrace deposits	

UNCONFORMITY

TRIASSIC	Gettysburg Fm.	Diabase intrusives
	New Oxford Fm.	

UNCONFORMITY

			CUMBERLAND VALLEY SEQUENCE		LEBANON VALLEY SEQUENCE
ORDOVICIAN	*Trentonian*		Martinsburg Fm.*		Martinsburg Fm.*
			basal limestone unit		Hershey Fm.
			Chambersburg Fm.		Myerstown Fm.
	Black River		? ▨ ? ?		▨
	Chazyan		ST. PAUL GP.		▨
					Annville Ls.
	Canadian	BEEKMANTOWN GP.	Pinesburg Station Fm	BEEKMANTOWN GP.	Ontelaunee Fm.
			Rockdale Run Fm.		Epler Fm.
			Stonehenge Fm.		Rickenbach Dol.
			Stoufferstown Fm.		Stonehenge Ls.
CAMBRIAN	*Upper*	CONOCOCHEAGUE GP.	Shadygrove Fm.	CONOCOCHEAGUE GP.	Richland Fm.
			Zullinger Fm.		Millbach Fm.
					Schaefferstown Fm.
					Snitz Creek Fm.

* Includes allochthons of Taconic affinity.

Figure 2. Generalized table of formations in the Harrisburg area. Those units not present in the mapped area are shown by pattern.

its extremely limited possible occurrence, it is not discussed on the legend of the geologic map (Plate 1).

Conococheague Group

The Conococheague Group (Root, 1968 and 1971) is divisible into the lower Zullinger Formation composed of 2,500 to 3,000 feet (760 to 915 m) of cyclical beds of intraformational limestone conglomerate*, stromatolitic*-oolitic* limestone, interbanded to interlaminated limestone and dolomite of algal-mat* origin, and supratidal* dolomite; and an upper Shadygrove Formation about 750 feet (230 m) thick composed of pure, light-colored, micritic* to micrograined* limestone, stromatolitic in part, with abundant pinkish limestones and large nodules of cream to light-brown chert. In eastern Cumberland County the two formations intertongue through several hundred feet so that selection of the contact is difficult there.

Rocks of the Shadygrove Formation probably comprise most of what is mapped as undifferentiated Conococheague Group (Plate 1). Near Wesley Drive, at the base of a ridge formed by the overlying Stoufferstown Formation, uppermost beds of the Shadygrove crop out in several places and are composed of very light gray, micritic limestone, partly with a marbleoid texture and pinkish cast, that contains abundant *Cryptozoon*-type stromatolites and nodules of light-brown chert. The chert contains molds of what are probably glauberite and halite, indicating a peritidal* sabkha* environment. In the mapped area the Shadygrove forms a broad valley with only a few isolated ledges of a lithology that tends to confirm the presence of this formation.

Beekmantown Group

The Beekmantown Group consists of four formations, which in ascending order are the Stoufferstown, Stonehenge, Rockdale Run, and Pinesburg Station Formations.

Stoufferstown Formation

The Stoufferstown Formation is both a ridge former and of such distinctive lithology that it is one of the key mapping units in the carbonate terrain. These unique characteristics are maintained with virtually no change from Franklin County (Root, 1968 and 1971).

The Stoufferstown Formation forms a continuous narrow ridge that contrasts with the flat valleys formed by the underlying Shadygrove Formation and the rolling valleys formed by the overlying Stonehenge Formation. The contact with the Shadygrove is sharp, but the contact with the Stonehenge is locally gradational.

The Stoufferstown throughout the entire Cumberland Valley is composed dominantly of carbonate detritus with particles ranging from clay to cobble size; tabular limestone fragments commonly 2 to 3 inches (5 to 8 cm) long characterize this facies, forming thin beds of distinctive edgewise* conglomerate. Many beds are oolitic. Yellowish-tinged dark-gray-weathering seams with a high quartz sand content, in places cemented by secondary silica, characteristically weather in sharp relief (Figure 3). Bright-orange-weathering patches of dolomite, half an inch (1.3 cm) or less in diameter, are a distinctive feature. The siliceous seams are important in the recognition of the Stoufferstown as they form a distinctive lithology. These seams underlie the ridges, and where they do not crop out, they form a surficial soil composed of dark-colored hard shaly chips. This type of seam also occurs infrequently near the top of the Zullinger Formation, but in that formation is not intimately associated with intraformational conglomerate, especially the edgewise conglomerates, so typical of the Stoufferstown Formation. Good exposures occur near Wesley Drive and Orchard Crest (Plate 1).

At a number of localities calculations based on width of outcrop indicate that the Stoufferstown is approximately 200 feet (60 m) thick. This compares favorably with a thickness of 220 feet (67 m) at Chambersburg (Root, 1968).

Stonehenge Formation

It is difficult to establish an internal stratigraphy or compute a reliable thickness for the Stonehenge Formation as outcrops are extremely sparse

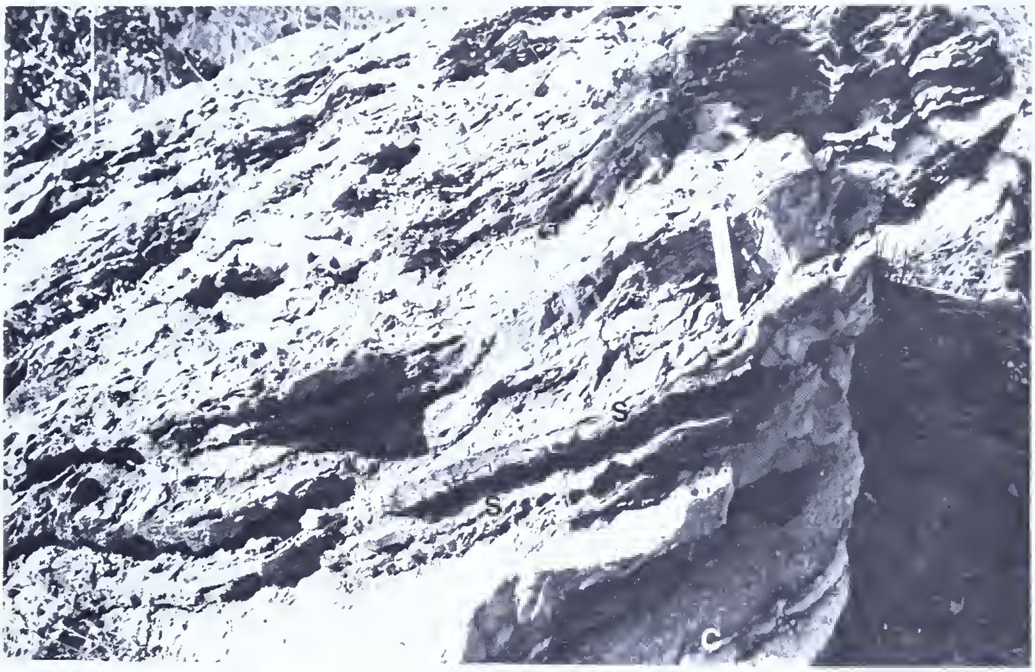


Figure 3. Typical aspect of the Stoufferstown Formation. Note dark siliceous seams (s) that weather in prominent ridges, and intraformational limestone conglomerate (c). Scale is 6 inches (15.25 cm).

in the mapped area. In the adjacent Mechanicsburg quadrangle exposures are more abundant, and on the basis of outcrops there and in the mapped area, a gross stratigraphy is derived.

In the mapped area exposures of the lower part of the Stonehenge Formation occur along the Pennsylvania Turnpike. These rocks are micritic to micrograined, light-gray limestone with abundant patches of very fine grained, detrital* micritic and skeletal*-detrital micritic limestone. Closely spaced, crinkled, siliceous dolomite laminae occur throughout. Some 1- to 3-foot- (0.3- to 0.9-m-) thick beds of massive buff-weathering dolomite containing sparse black chert nodules occur as interbeds in the limestone. The presence of dolomite interbeds is of significance because to the south (Root, 1968 and 1971) these are absent, and indeed their absence to the south is one of the mapping criteria that distinguishes the Stonehenge Formation from the Rockdale Run Formation.

In the outcrop belt northwest of Rossmoyne Manor there are a few outcrops of the upper part of the Stonehenge Formation. These are thinly bedded, light-gray to very light gray, very fine grained, detrital micritic and skeletal-detrital micritic limestones with medium-gray crinkled siliceous dolomite laminae. They weather into isolated pyramids that protrude up to several feet above general ground surface. From the float it appears that the stratigraphically highest Stonehenge limestone beds become lighter colored and micritic.

The upper contact of the Stonehenge Formation is placed below where the micritic limestones become stromatolitic in part, have a reddish cast when wetted, and bear large light-gray to pale-buff chert concretions. In Franklin County (Root, 1968 and 1971) these light-colored chert-bearing stromatolitic micritic limestones form the base of the overlying Rockdale Run Formation and are readily distinguished from the Stonehenge. However, in the mapped area, the contact between the Stonehenge and Rockdale Run appears less distinct, and the position of the contact, to some degree, is open to question.

In the Mechanicsburg quadrangle the Stonehenge, over a considerable area, is composed of light-gray to pinkish-buff micritic stromatolitic limestones with larger buff chert nodules, so that it is similar to parts of the Shadygrove and Rockdale Run Formations. These limestones grade laterally into more typical, thin-bedded, very fine grained, detrital micritic Stonehenge-type limestones. It appears that, in tracing the Beekmantown Group north from Franklin County, the Stonehenge Formation passes through more profound lithofacies variations than the other formations in the Beekmantown and these variations may be divisible into mappable members. It may be that the term Stonehenge should not be used in eastern Cumberland County.

On the basis of outcrop width and dip of beds the Stonehenge Formation is estimated to be about 400 to 500 feet (120 to 150 m) thick. This figure may be questioned as the upper limit is selected with considerable uncertainty; however, as the Stonehenge is about 550 feet (168 m) thick to the south (Root, 1971), this thickness seems plausible.

Rockdale Run Formation

Rocks of the Rockdale Run Formation extend across a considerable portion of the mapped area. Exposures are sparse in the lower part of the unit, but are relatively abundant in the upper part. The formation is composed of limestones and minor beds of dolomite. Although there is no section that was measurable, the lithologic succession of the formation can be described in general terms.

Approximately the lower quarter to third of this formation contains considerable amounts of medium-bedded, very light gray to subtle pinkish gray, finely laminated to homogeneous micritic limestone. In instances there is a pronounced pinkish color, especially when wetted, and frequently, vague to fairly well defined stromatolitic structures are preserved. Large very light gray to buff-colored chert nodules occur as both rounded and blocky cobbles and boulders in fields. From observations in Franklin County (Root, 1971) it appears that the cherts are associated with the stromatolitic horizons. As noted previously, the contact with the underlying Stonehenge Formation is difficult to select because of lithologic similarity and poor exposure.

The upper two thirds to three quarters of the Rockdale Run Formation consists principally of light-gray, medium- to thick-bedded, detrital limestones to detrital skeletal micritic-micrograined limestones. The detrital fragments may range up to pebble size, and texturally these limestones are breccias (Figure 4). The lower portions are composed of thick-bedded, medium- to coarse-grained, detrital and skeletal intraclasts in a micritic to micrograined matrix. Locally there is an admixture of recognizable fossil grains and larger fragments. Poorly preserved banded, laminated, or vague "Collenia"-type stromatolites also occur. Buff-orange- to brown-weathering, argillaceous, silty dolomite interbands are spaced from a few inches to a couple of feet throughout the limestones and weather in relief. Thick beds of buff-brown-weathering dolomite are sparsely distributed throughout this sequence. In the upper portions light-gray-weathering, thin- to medium-bedded, micrograined to rarely micritic limestone, locally with fine- to medium-grained detrital, skeletal, and stromatolitic components, occurs. Crinkled dolomitic laminae occur throughout. These beds weather into pyramidal forms and in total aspect are similar to the Stonehenge Formation.

The upper 195 feet (60 m) of the Rockdale Run Formation is described in the measured section (Appendix 1). In these beds bioturbated limestones appear in quantity, and white "cauliflower-shaped chert" rosettes are abundant (Figure 5). The rosettes are composed of microscopic milky

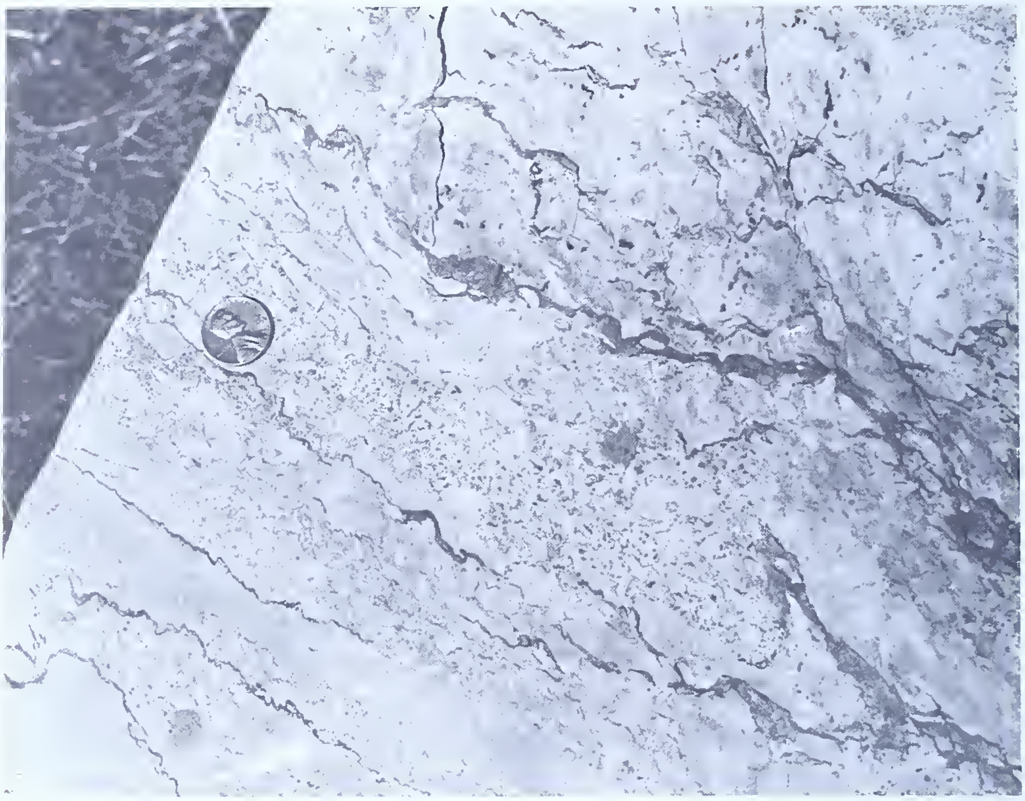


Figure 4. Typical skeletal-detrital limestone of the Rockdale Run Formation. The tabular character of the limestone intraclasts forms nearly a breccia texture. Considerable flowage of the rock and stylolite development has occurred. Note coin for scale.

quartz grains in a banded concentric structure, but as an informal field term have been referred to as "chert." These distinctive and unique rosettes are especially important as they frequently form abundant small chips in fields and aid in mapping the uppermost beds of the Rockdale Run. In cuts along the Penn Central Railroad at Lemoyne the rosettes appear to be absent at this horizon, but this is interpreted as only a local aberration as the rosettes appear to be common in the Cumberland Valley.

Regionally the Rockdale Run Formation is conformable with the overlying Pinesburg Station Formation. The contact is selected where the predominant limestones of the Rockdale Run pass into the predominant dolomites of the Pinesburg Station. Where the latter is principally dolomite, as in the measured section (Appendix 1), the distinction is clear, but in some instances there are a considerable number of limestone interbeds in the basal portion, so that the contact may be somewhat arbitrary.

Estimation of thickness based on width of outcrop and dip indicates that the Rockdale Run Formation is about 2,000 to 2,500 feet (600 to 750 m) thick. This is a reasonable estimate as the formation is 3,000 feet

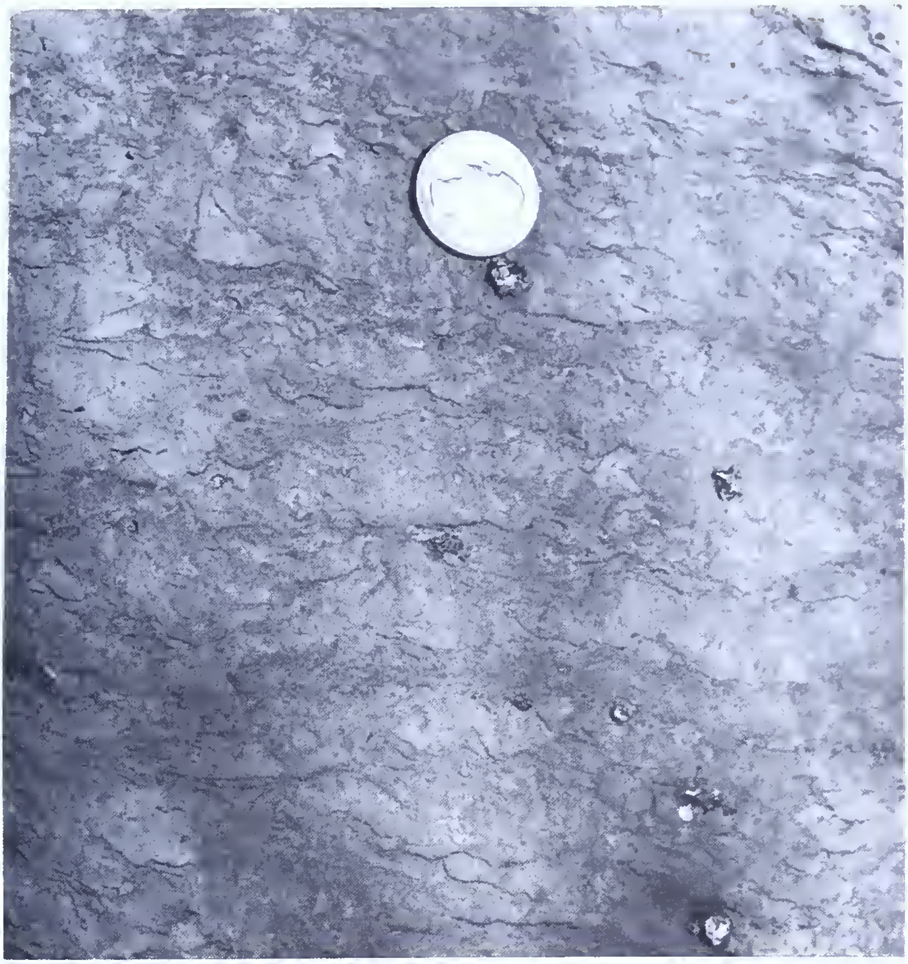


Figure 5. Limestone with burrowed structure and protruding blebs of white chert and rosette quartz. Uppermost part of Rockdale Run Formation. Coin on rosette gives scale.

(900 m) thick at Chambersburg (Root, 1971) and is believed to thin towards Harrisburg (Stose, 1953).

Pinesburg Station Formation

The Pinesburg Station is composed of massive beds of dolomite that weather light gray to medium light gray with a darker hue. These beds are sparsely laminated to banded (Figure 6) and frequently are homogeneous. In the lower part, thin white quartz rosettes and some larger nodules of black to dark-gray chert occur. A few medium beds of bluish-gray limestone interbeds are present. These dolomites generally are somewhat lighter in color than dolomites elsewhere in the section, and are characterized in the field by closely spaced fractures. The formation is described in detail in the measured section (Appendix 1).

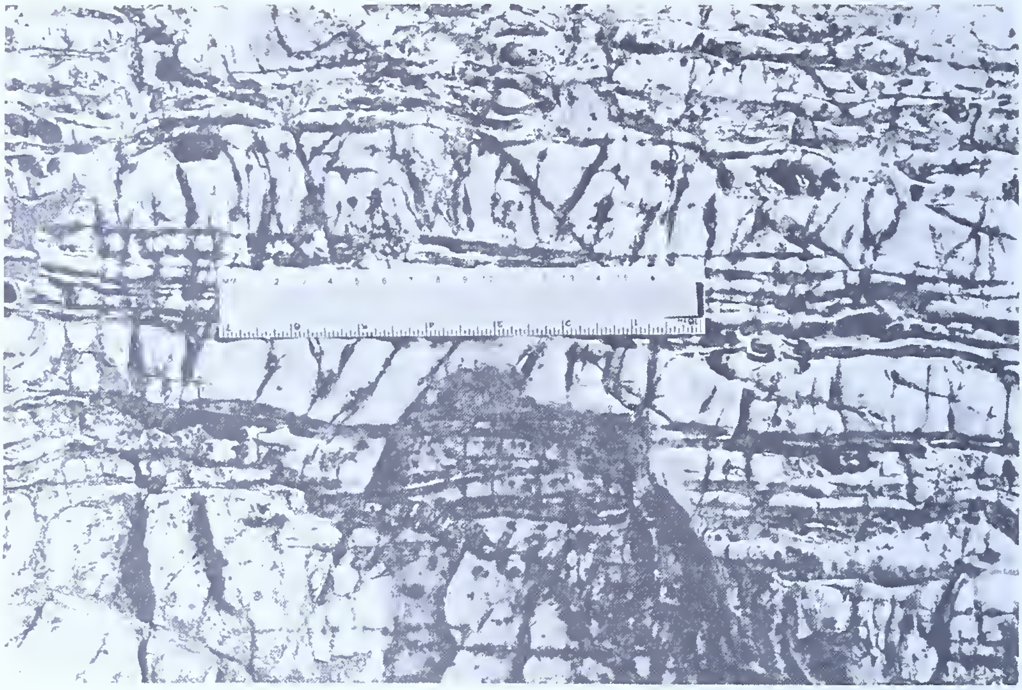


Figure 6. Finely laminated light-gray to medium-light-gray dolomites of the Pinesburg Station Formation.

At the measured section the Pinesburg Station Formation is 208 feet (63 m) thick. Two other localities in the area permitted estimation of thickness based on width of outcrop and dip of beds. Along cuts of the Penn Central Railroad in Lemoyne a thickness of about 175 feet (53 m) was calculated. In the belt of dolomite east of the interchange at the Harrisburg Expressway and U. S. Route 15, a thickness of about 300 feet (90 m) was calculated. These values are in substantial agreement with a thickness of about 250 feet (75 m) measured near Chambersburg (Root, 1971) and 350 feet (110 m) computed just north of Carlisle.

St. Paul Group

The St. Paul Group is of considerable importance because the high-calcium limestones quarried in the Great Valley are principally derived from this unit or its equivalents. It is moderately well exposed in the mapped area, and a complete section 580 feet (177 m) thick was measured (Appendix 1) on the extreme west edge of the quadrangle at the northwest corner of the Mechanicsburg Naval Supply Depot.

Light-gray micritic limestone, frequently with a network of darker, clear calcite spar that imparts a "birdseye" fabric to the rock, is a distinctive component of the strata (Figure 7). These beds are of high-calcium quality. Other lithologies typical of this group are bioturbated* limestones; limestones with black chert nodules; dolomite interbeds; and

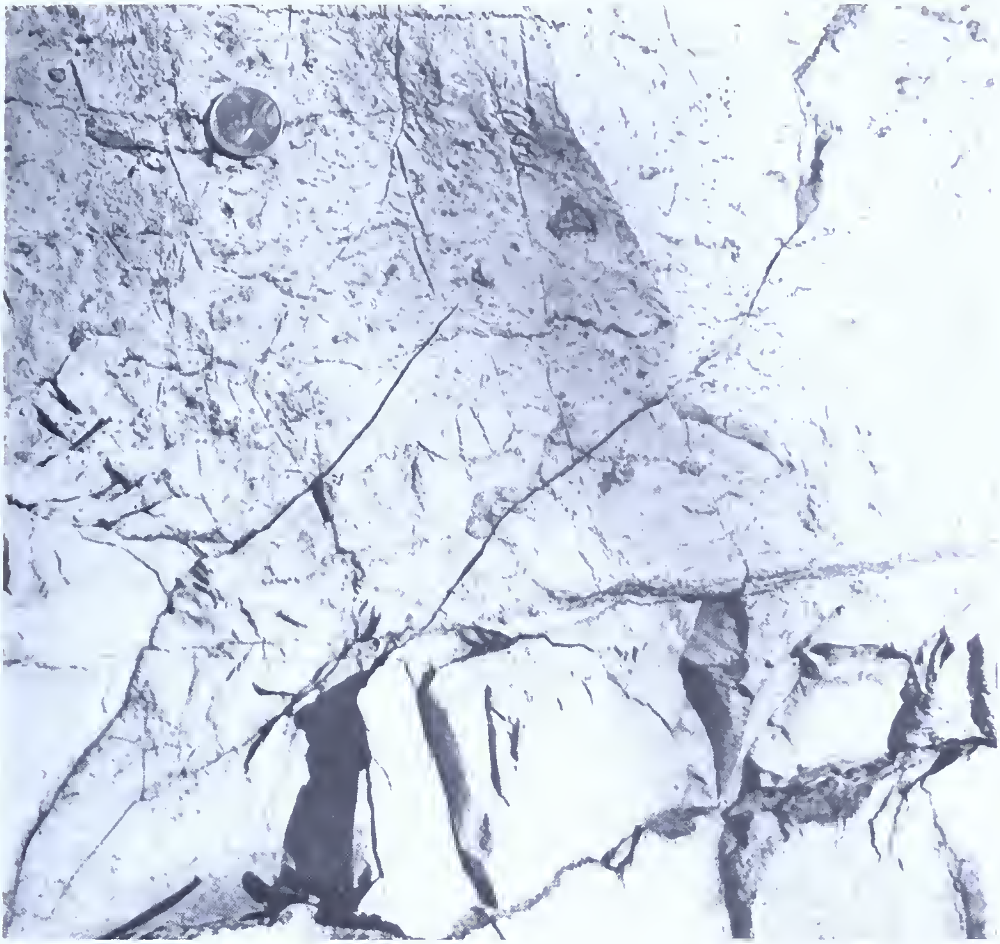


Figure 7. High-calcium micritic limestones from the basal part of the St. Paul Group. Network of clear calcite spar, subparallel to bedding, weathers in slight relief and imparts a "birdseye" fabric to the rock.

detrital limestone with varying amounts of skeletal material including large orthocerids. Several beds of pink micritic limestones with pink chert occur at the Hempt Bros. quarry along Yellow Breeches Creek.

A partial section measured by Prouty (1960, p. 91-96) at Lemoyne is 558 feet (170 m) thick. However, this has been extended by MacLachlan (1967, p. 142), who computed a thickness in excess of 900 feet (275 m) by assuming that the beds called transitional to Beekmantown by Prouty are included in the St. Paul. Comparison of this section with the section at the Naval Supply Depot illustrates the complex facies changes in the St. Paul Group, as the Lemoyne section is undoubtedly thicker and contains significantly more dolomite interbeds. The unit is about 1,000 feet (305 m) thick in southeastern Franklin County (Root, 1968) and about 920 feet (280 m) near Carlisle, of which 687 feet (210 m) is described by Prouty (1960, p. 84-88).

The economic potential of this unit is discussed in the section on mineral resources.

Chambersburg Formation

The Chambersburg Formation is poorly exposed in the mapped area and is of extremely limited extent. In the adjacent quadrangle outcrops are better, and Dyson (1967, p. 8-9) has described the stratigraphy in some detail. At the top of the Chambersburg is 120 feet (37 m) of dark-gray, very fine grained, platy limestones 0.5 to 5 inches (1.3 to 13 cm) thick that Dyson (1967) assigns to the Oranda Formation. Above this is an undetermined thickness of grayish-black, laminated, argillaceous and silty limestones assigned to the Hershey Formation. Both terms are considered invalid here, and the rock units assigned to the "Oranda" and "Hershey" Formations are included in the basal limestones of the Martinsburg Formation.

The following description of the Chambersburg is based on Dyson's (1967, p. 8-9) studies in the adjacent quadrangle:

> The limestones of the lowermost 150 feet [46 m] of [the Chambersburg Formation at] the Sample Bridge section are largely dark gray, even bedded, and dense. Between these beds are thin but prominent layers of darker, argillaceous limestone. Above these strata is a section, 335 feet [102 m] thick, of dark-gray, thin-bedded (2 to 3 inches [5-8 cm] mainly), fine-grained, nodular limestone with thin but conspicuous nearly black shaly partings between layers. Several metabentonite[*] zones, the lowermost of which is nearly 2 feet [0.6 m] thick, are present. Fossils, especially brachiopods, are abundant in certain horizons. Above this are 170 feet [52 m] of dark-gray- to medium-dark-gray, fine-grained, thin-bedded, (1 to 7 inches [2.5 to 18 cm] largely) fossiliferous limestone with argillaceous partings between beds. This section is even bedded in the lower part and nodular in the upper. At least five metabentonite zones are present in the upper part.
>
> These 650 feet [198 m] of strata, characterized chiefly by the nodular character and abundance of argillaceous partings, apparently are . . . the Chambersburg Formation . . . .
>
> At least six metabentonite zones were identified in the Chambersburg Formation . . . .
>
> The unweathered metabentonite has a light-yellowish-olive, yellowish-gray, or pale-olive color. In some zones it is extremely fine grained; in others its texture is very fine granular and small mica flakes are visible. Metabentonite samples from several of the units . . . yielded X-ray diffraction patterns indicating significant amounts of quartz and montmorillonite.
>
> The metabentonite varies in thickness from ½ inch to 13 inches [1.3 to 33 cm] and is overlain in most cases by a dark-gray, noncalcareous layer varying between 1 and 9 inches [2.5 to 23 cm] in thickness. Thin layers and lenses of quartz and calcite are associated with some of these horizons, and two metabentonites in the Pennsy Quarry contain abundant small pyrite cubes.

The Chambersburg is apparently conformable with the underlying carbonate rocks of the St. Paul Group. This relationship is demonstrable at the Sample Bridge locality of Dyson (1967), where argillaceous limestones of the Chambersburg abruptly overlie the high-calcium, lighter colored, micritic limestones of the St. Paul Group. The contact with the Martinsburg is gradational, and the thin-bedded limestones mapped at the base of the Martinsburg reflect the basinal transition from dominately carbonate sedimentation to dominately clay deposition.

Martinsburg Formation

The Martinsburg Formation in the Harrisburg area consists of several distinct rock types of complex origin, in contrast to the principally pelitic turbidite sequence at its type area and into Franklin County (Root, 1968 and 1971). Several rock types are mapped separately within the body of the Martinsburg Formation, but only informal names are applied.

Lower basal Martinsburg consists of laminated platy argillaceous limestone in beds 1 to 4 inches (2.5 to 10 cm) thick interbedded with calcareous to noncalcareous shales that are silty in part and in beds 0.5 to 2 inches (1.3 to 5 cm) thick (Figure 8). Towards the base are a few 1- to 2-inch- (2.5- to 5-cm-) thick beds of medium-orange-brown dolomite to dolomitic shale and graded subgraywacke beds. In the middle part of the unit are a few lenses and knots, 0.25 to 2 inches (0.6 to 5 cm) thick, of black chert that locally weathers light gray. The amount of lime both as limestone beds and calcareous shales progressively decreases upwards in this unit, and the amount of shale increases. Fine-grained graywacke to subgraywacke interbeds appear towards the top. This unit is estimated to be at least several hundred feet thick, although isoclinal folding and faulting throughout the unit makes this estimate highly speculative. The top of the unit is arbitrarily selected at the occurrence of some thick subgraywackes and graywackes, or, if these are absent, where the lime content is negligible. The lowermost part of the unit in contact with the Chambersburg is not exposed in this area but is exposed to the east in the New Bloomfield quadrangle (Dyson, 1967), where the relationship appears to be conformable and gradational. These lowermost beds are dominantly composed of argillaceous limestone 1 to 6 inches (2.5 to 15 cm) thick and, as noted previously, probably merit distinct formational or member status.

The main body of the Martinsburg is a dark-gray shale, silty in part, with some thin interbeds of siltstone and locally thin interbeds of fine-grained graywackes and subgraywackes. It characteristically weathers in medium-orange-brown plates or chips.

From Carlisle eastward the main body of Martinsburg dark-gray shales is in large measure supplanted along strike by several allochthonous lithologic units: coarse thick-bedded graywackes; platy limestones; limestone conglomerates; calcareous quartz sandstones; micaceous maroon and minor green mudstones; green, green-gray, and medium- to dark-gray

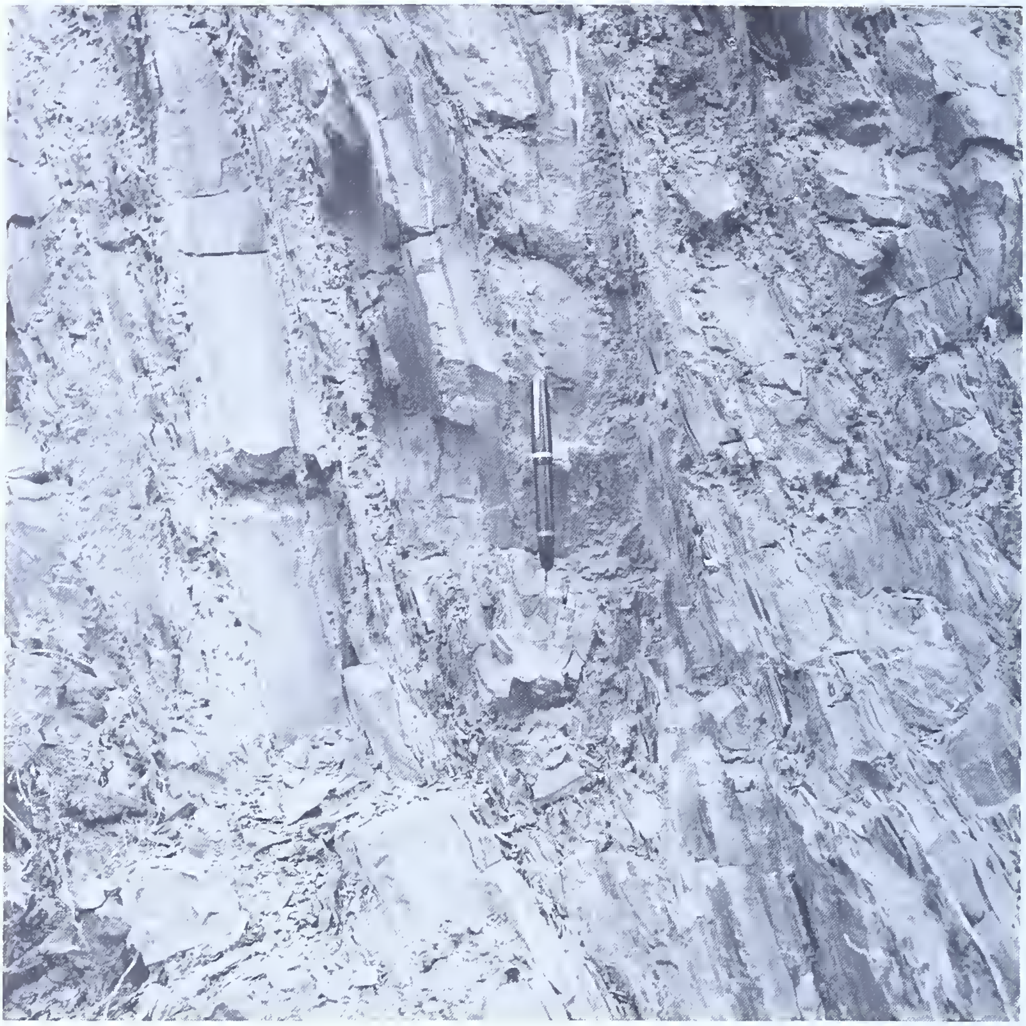


Figure 8. Autochthonous basal limestones of the Martinsburg Formation. Beds are in a series of isoclinal folds; pen is in the hinge of a syncline. At Sporting Hill Road along Conodoguinet Creek; Figure 27b presents structural data from this location.

shale; and massive gray cherts. The presence of older allochthonous masses of rock incorporated into the Martinsburg in the Harrisburg West area was first observed by Stose (1930, 1946). It has been proposed (Platt and others, 1972) that these varietal units were introduced by gravitational tectonics into the depositional basin as lithified masses derived from a terrain of older rocks to the east—possibly a western extension of the Taconics.

It is probable that the ultimate extent of the allochthonous strata and their sequence of incursion will only be determined by detailed paleontologic studies of well-zoned microfossils; structural studies and lithic assemblages are only a partial key to the deciphering of internal relations within this complex body of rocks. For convenience, these allochthonous rocks are shown on the columnar legend to occupy a specific stratigraphic position. It should not be inferred that these allochthonous rocks constitute a stratigraphic succession within the normal geologic context; however, they may approximate the sequence of introduction of allochthonous masses into the basin.

The internal stratigraphy and structural history of the Martinsburg is so complex that it is virtually impossible to compute a thickness. It can only be postulated that the Martinsburg is at least several thousand feet thick in the mapped area.

Allochthonous Units

Allochthonous lithic varietal units are restricted in distribution and association and are therefore able to be grouped as discrete assemblages. These assemblages constitute allochthons of the type described by Zen (1972) in similar rocks of the Taconide Zone in the northern Appalachians and are probably of paraklippe* and klippe* affinities.

Enola Allochthon. This is the most extensive allochthon in the mapped area. It is characterized by abundant red mudstones and gray limestones enclosed in greenish and greenish-gray shales and mudstones. Extending across the mapped area and well into the southern New Bloomfield area (Dyson, 1967) on the west are several thin horizons of pale-red to maroon, silty, abundantly coarsely micaceous mudstones with several local brownish-red sandstones. Locally some beds are entirely green or exhibit greenish partings, or contain small greenish shale chips in a red matrix. These beds are as much as 30 feet (10 m) thick in the Harrisburg area but thin westward to less than 3 feet (1 m) thick. Intimately associated are tough green and greenish-gray to grayish-green coarsely micaceous mudstones.

Closely associated with the red beds are several very thin limestone horizons. Although the individual limestones are of limited lateral extent, as a belt they extend across the mapped area and persist to Carlisle (Dyson, 1967), where they become locally conglomeratic and arenaceous. In the mapped area the limestones are less than 20 feet (6 m) thick and are composed of platy-weathering 1- to 2-inch (2.5- to 5-cm) beds of distinctive grayish-yellow-buff-weathering, dark-gray, micritic to micrograined, argillaceous limestones, occasionally with silty streaks. They are sharply interbedded with 1- to 2-inch- (2.5- to 5-cm-) thick bands of black fissile limy shale. These limestones are distinct from the basal autochthonous limestones of the Martinsburg Formation.

Much of this allochthon is composed of greenish-gray and grayish-green phyllitic shale, fissile to nonfissile, with sparse fine mica. Medium-to dark-grayish shales occur as thick interbeds, especially at the southern margin of the allochthon, and these may in part be autochthonous Martinsburg, so that the contact is locally speculative.

A single occurrence of massive gray chert just west of the mapped area in the Wertzville quadrangle (40°16′42″N/77°00′06″W) is of particular interest. This is the only occurrence of chert recognized in the area between the Susquehanna River and Carlisle. It is apparently restricted in occurrence to an isolated hill, several hundred feet long, that has the highest elevation in this belt of Martinsburg. Although there is no outcrop, the large blocks of float that litter the hill attest to the fact that it is primarily composed of chert. The chert is principally light gray in color, and what appear to be chertified pellets and lumps are discernible, suggesting that it may be a replaced limestone. The singular occurrence of this rock type is evidence for the allochthonous nature of portions of the Martinsburg Formation.

Summerdale Allochthon. This allochthon is of limited extent in the mapped area, occurring as a small belt along the Susquehanna River. An extremely varied sequence of rocks is present. The most distinctive is a 150-foot- (45-m-) thick sequence of arenaceous conglomeratic limestone (Figure 9) and platy limestones interbedded with black shales (Figure 10) in the Penn Central Railroad yards at Enola (Appendix 2). Along strike on the west this lithology becomes more arenaceous and extends for only 2,000 feet (600 m) before it disappears abruptly; to the east it thickens markedly and is about 500 feet (150 m) thick where Interstate 81 crosses Wildwood Lake in Harrisburg. Associated with these carbonate rocks is a series of hackly maroon mudstones.

In cuts behind the Summerdale Plaza a series of exposures superbly demonstrate the internal complexity of this allochthon. The strata are composed principally of dark-gray fissile shale with abundant beds of green and greenish-gray shale and medium-thick beds of buff graywacke. Beds of siderite, limestone conglomerate, and soot-black shales to 6 inches (15 cm) thick also occur, as do thinner dark-gray chert bands. The more competent beds are disrupted, occurring as isolated blocks ranging in size from a few centimeters (limestone, siderite, and chert) to several meters (graywacke and some red mudstones). Some of the disrupted beds exhibit isoclinal folding that appears to be soft-sediment deformation. The gross aspect of these exposures is that of a highly sheared body of rock of mélange* character.

Isolated exposures in this allochthon are composed of greenish to medium-gray shales with interbeds of calcareous graywackes 2 to 24 inches (5 to 60 cm) thick.

Mixed Terrain. The probable occurrence of autochthonous horizons

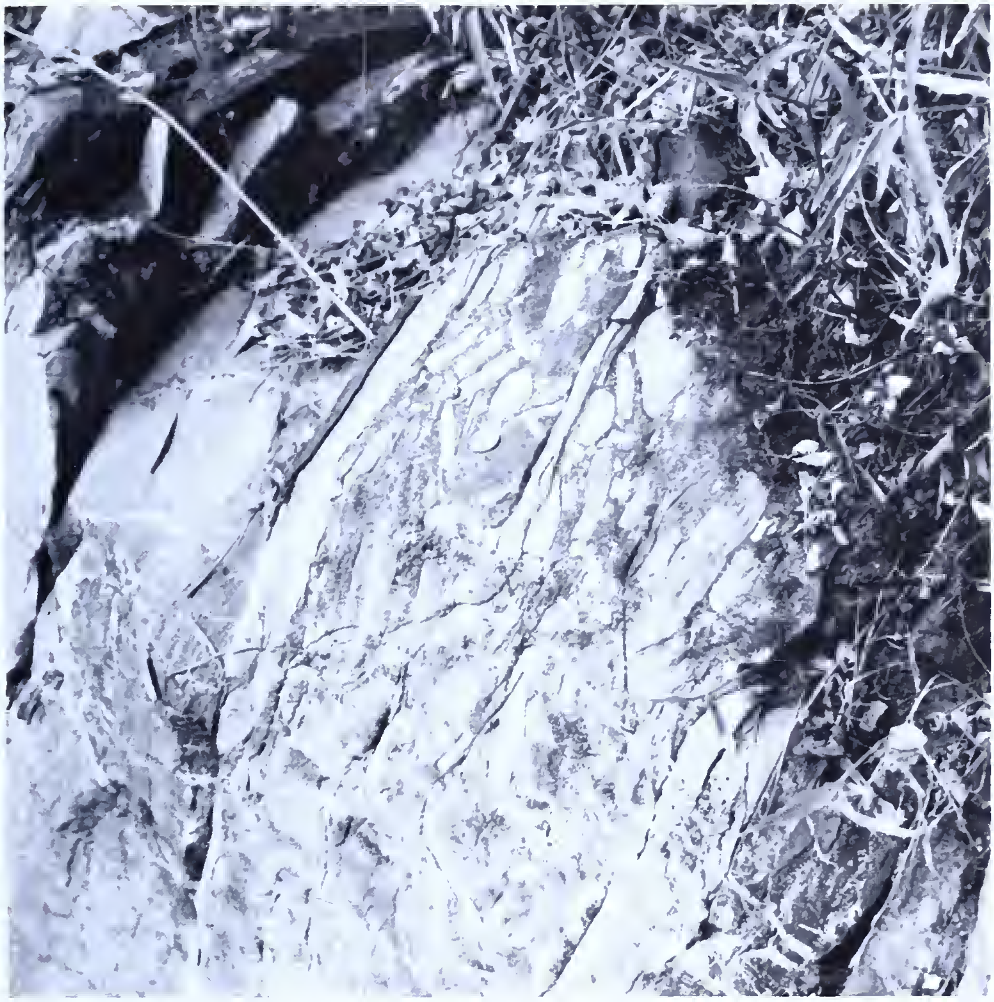


Figure 9. Allochthonous conglomeratic limestone in matrix of quartz grains and calcite, Summerdale allochthon. Note coin for scale. In railroad cuts at Enola.

within the areas mapped as allochthon was previously noted, but they are probably a minor constituent. In the areas designated as mixed terrain lesser amounts of allochthonous strata are intimately mixed with autochthonous strata so that it is difficult to distinguish among them, and the terrain is best mapped by its heterogeneity.

In the eastern part of this belt of mixed terrain, allochthonous material appears to dominate over the autochthonous material; however, as undistinguished medium-gray shales and siltstones with minor graywackes make up much of the terrain it is difficult to assess relative amounts with any precision.

Some allochthonous graywackes can be recognized on a structural basis. At the bend in Center Street where it leaves the Conodoguinet floodplain and ascends the bluff toward Enola (40°16′20″N/76°56′30″W),

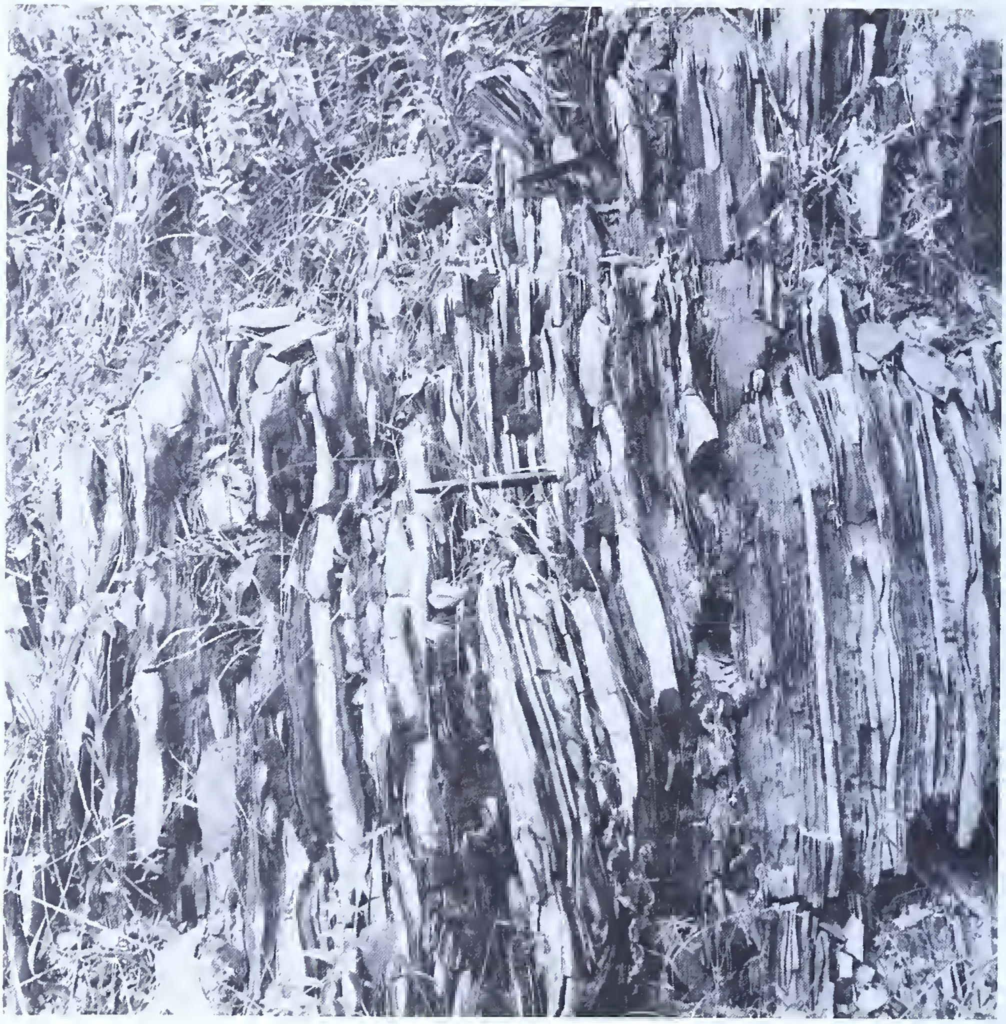


Figure 10. Allochthonous interbanded platy limestones and fissile black shale of the Summerdale allochthon in railroad cuts at Enola.

complexly folded and disrupted graywackes are exposed in the roadcut. Some isolated fold hinges show an early, and presumably S_1, axial plane cleavage inclined to the prominent South Mountain cleavage (S_2). These graywackes then are clearly allochthonous because the autochthonous rocks have only cleavage. Relation of cleavage to bedding indicates that parts and possibly much of the allochthonous masses were emplaced on/in the autochthonous shale in a grossly inverted position.

In the western part of this belt the mixed terrain is probably composed in larger part of autochthonous rocks. It is so surmised, partly on a conceptual basis, because the allochthonous rocks decrease westward and partly because of the lack of clearly recognizable allochthonous masses. The rocks in this terrain are principally medium-gray shale and thin siltstone, presumably autochthonous, and some green-gray phyllitic-micaceous shales, presumably allochthonous.

The complexity of distribution of allochthonous-autochthonous shales is well shown along Good Hope Road where it is crossed by Interstate 81. The hill immediately south of the interstate is composed of presumably allochthonous, phyllitic, micaceous, green-gray shales that weather orangish buff. At the base of the hill are presumably autochthonous, medium-gray shales with two cleavages. North of the hill roadcuts on Interstate 81 include some highly folded, dark-gray shales (autochthonous?) with multiple cleavages, containing limestone pebbles and blocks of other rock. Possibly the introduction of the Enola allochthon produced the first cleavage in the darker autochthonous (?) shales.

Yellow Breeches Klippe. Centered about the confluence of Conodoguinet Creek and the Susquehanna River is a geographically limited sequence of allochthonous rocks that exhibit reoriented structures similar to those of the Yellow Breeches thrust sheet.

A unique type of allochthonous graywacke occurs in the klippe. The graywackes are well graded, exhibiting several elements of the Bouma cycle*, medium to dark gray in color, with green shale chips and very fine quartz pebbles at the base of the bed. The matrix is limy and the beds weather a dark rusty brown. The coarse grain size and great bed thickness (up to 10 feet (3 m)) distinguish these strata from other graywackes in the mapped area. They grade up into hard silty dark-gray shales which may be as much as 20 feet (6 m) thick. Best exposures of this lithology are along the road facing the Susquehanna River in West Fairview and in the rock ledges formed by the graywackes in the river bed.

In cuts of the Penn Central Railroad on the south side of Conodoguinet Creek the graywackes are sparser and thinner. At the south end of the cut abundant thin beds of semi-micritic dark-gray argillaceous limestones are abundant. Reorientation of bedding is intense here, strata are all tectonically disrupted, and these may actually be autochthonous Martinsburg basal limestones below the thrust plate.

The reoriented structures developed within the base of the thrust sheet or immediately beneath the sheet. On the basis of the limited extent of these lithologies the beds are considered to be within the Yellow Breeches sheet and represent an erosional outlier. These are allochthonous rocks of Martinsburg in the Lebanon Valley nappes that have been emplaced along the Yellow Breeches thrust onto a Martinsburg mixed terrain much later than the original introduction of allochthonous masses in the Martinsburg of the Cumberland Valley sequence—it is in effect a twice travelled allochthon.

LEBANON VALLEY SEQUENCE

As noted in the introduction, the rocks of the Yellow Breeches thrust sheet are part of the Lebanon Valley stratigraphic sequence and constitute a distinct and separate stratigraphy from the rocks that they override in the Cumberland Valley sequence. Although the two rock sequences are correlatives, they represent deposition in widely different parts of the Appalachian Basin.

Parts of three formations of the Lebanon Valley sequence are present in the mapped area (Figure 2). Each formation is bounded by faults, so that only a small portion of total formation thickness is present. However, eastward into Dauphin County the Yellow Breeches thrust sheet becomes more extensive and has fewer internal faults; MacLachlan (1967) was able to describe in some detail the entire stratigraphy of each formation. Calculation of formational thickness is difficult because of generally poor outcrop and complex multiple deformations, including regional stratigraphic inversion and development of a pervasive tectonite* fabric that obliterates primary structures.

Epler Formation

Probably only a few hundred feet of the upper part of the Epler Formation is present in the mapped area. The outcrop belt is limited on the northwest by an extensive thrust fault and locally by a normal fault, and limited on the southeast by overlap of the Triassic sediments.

In Dauphin County, according to MacLachlan (1967), the Epler Formation consists of medium- to thick-bedded, distinctly laminated, finely crystalline limestone with subordinate interbeds of thin- to medium-bedded, homogeneous to faintly laminated, medium-dark-gray, grayish-yellow-weathering, finely crystalline dolomite and magnesian limestone (Figure 11). The dolomite is apparently fairly uniform in character throughout the section, but varies in abundance both stratigraphically and along strike. The intense jointing of the more brittle dolomites has had several effects: the weathered surface is rough and ropy; a boxwork of secondary milky quartz sometimes forms in joints, locally to the extent of almost complete replacement of the bed; and solution activity has to a large extent been concentrated along the fractured beds so that solution cavities are much more common in the normally less soluble dolomite beds.

In the upper part of the formation almost all the limestone beds are medium light gray to medium gray, weathering light gray, with conspicuous yellowish-gray to grayish-brown, silty to argillaceous laminae. Irregularly mottled, partially dolomitized beds, in which the dolomitized material seems to occur in organic burrows, are occasionally present. At their tops a few limestone beds contain lenses of fossil fragments.

Many limestone beds in the lower part of the formation are similar to those in the upper part. In addition, light-gray to nearly white limestone

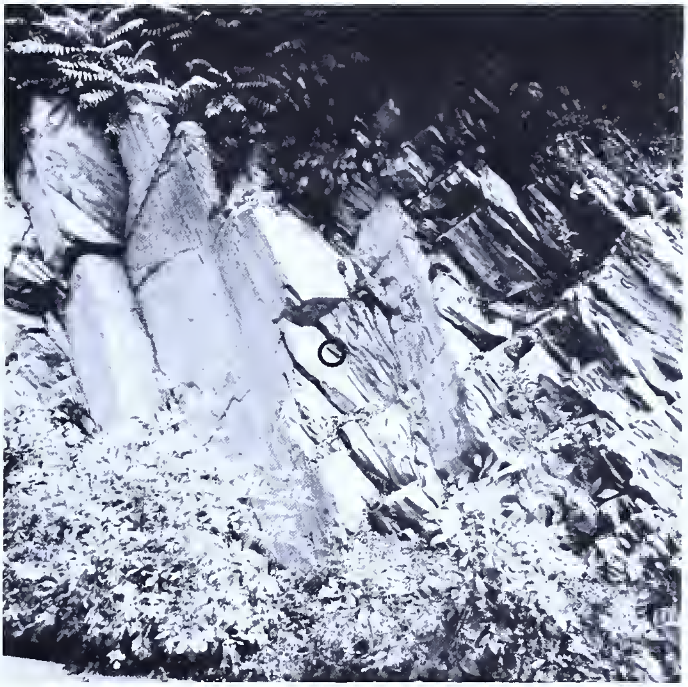


Figure 11. Thick-bedded limestone of the Epler Formation showing a well-developed bed-normal joint system. Pen (circled) indicates striping lineation (L_3) on S_1. In roadcut at Allendale.

beds are present, in which most laminations apparently reflect grain-size variations and concentrations of noncarbonate clastics. Other limestone beds have a distinct pinkish cast. At least two, and probably more, zones 1 to 6 feet (0.3 to 1.8 m) thick, carrying about 10 percent disseminated coarse quartz sand grains, occur in the lower part of the formation. Sparse nodular chert is present only near the base of the formation in Dauphin County, but is more abundant to the east. However, in the map area, abundant dark-gray and pinkish-gray chert occurs in association with light-pinkish-gray micritic limestones that are presumed to be in the upper part of the formation.

Myerstown Formation

Only a few tens of feet, stratigraphically, of the Myerstown Formation is present in the mapped area. This unit occurs in two narrow strips caught up between major faults on the Yellow Breeches thrust sheet that separate the carbonate rocks of the Epler Formation from argillaceous rocks of the Martinsburg Formation. The rocks designated as questionable Myerstown in the base of the thrust sheet may actually belong to the Hershey Formation or to basal limestones of the Martinsburg Formation.

According to MacLachlan (1967) the Myerstown is predominantly a thin, regularly bedded, medium-dark- to dark-gray, fine-grained, dense limestone which weathers medium to medium light gray with a distinct bluish cast (Figure 12). Very thin, dark shale beds interbedded with the limestones are sometimes present. Fossil fragmental calcarenite beds less than a foot thick have been recognized in a number of localities. Four thin metabentonite beds, indicative of volcanic ejections, occur in the upper half of the formation.

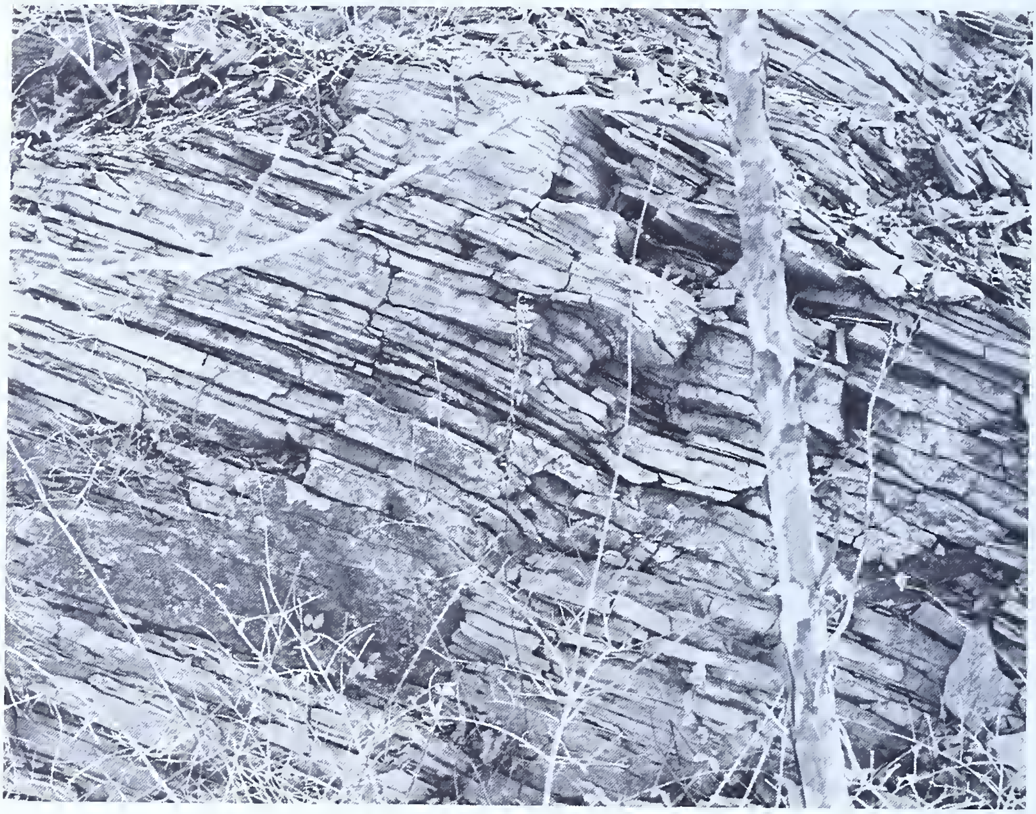


Figure 12. Thin-bedded limestones from the basal part of the Myerstown Formation.

Martinsburg Formation

The varied lithologies that characterize the Martinsburg Formation of the Cumberland Valley sequence are absent in the Martinsburg Formation on the Yellow Breeches thrust sheet. Principally, the Martinsburg on the Yellow Breeches plate is an argillaceous sequence composed of dark-gray, somewhat silty, phyllitic shales. The phyllitic character is a result of greater metamorphism of the Lebanon Valley sequence and is typified by a silky sheen on foliated surfaces resulting from recrystallized micas. The shales weather into buff-orange or brown, rarely reddish-brown or light-gray, chips somewhat similar to the habit of the shales of the Cumberland Valley sequence. Thin fine-grained graywacke or siltstone-sandstone bands occur sparsely. In a few places, clasts* of limestone or dolomitic limestone occur, but the calcareous nature of the enclosing matrix indicates that these are probably tectonically disrupted fragments of original beds. In general, foliation is so pervasive that little can be deduced about original bedding character or the extent to which allochthonous slices are present.

TRIASSIC

Triassic rocks in the Harrisburg West area are a red-bed sequence deposited in the Newark-Gettysburg Basin. The mapped area lies in the northern portion of the basin, in which only rocks of the Gettysburg Formation are present.

Gettysburg Formation

A number of distinct lithologic units are recognized but not named in the Gettysburg Formation, and their approximate distribution is shown on the geologic map (Plate 1). Although the units are shown as continuous belts they may actually be quite discontinuous. Maroon shales and mudstones form the bulk of the sedimentary rocks, within which quartz conglomerate, quartz-limestone conglomerate, limestone conglomerate, pebbly sandstone, and coarse-grained sandstone occur as tongues or lentils. The mudstones and shales are micaceous and silty, and locally have a calcareous cement. On fresh surfaces they are varying hues of red. Bedding is usually indistinct. Some thin siltstone beds are locally present and aid in defining bedding. These rocks weather easily, and extensive exposures are rare except in fresh roadcuts, as the rocks disintegrate readily upon exposure.

Tongues of pebbly sandstone and coarse-grained sandstone form uplands and ridges above the less resistant shales. Because of their lenticular nature and limited distribution formal names are not applied. The sandstones are composed of thick to massive beds of well-sorted medium- to coarse-grained quartz and are somewhat feldspathic. On a fresh surface they are red and weather reddish brown. Some red sandstones, probably with an originally calcareous cement, weather to gray or white friable sandstone blocks that litter slopes to the extent that they have been mapped as gray sandstone beds termed the Heidlersburg Member by Stose and Jonas (1939). However, this term may not be valid in the Harrisburg area as these sandstones are not uniquely gray but only intermittently weather gray, and nonred shales, which occur in the type area, are not present here. The pebbly sandstones contain abundant pebbles and cobbles locally, but these individual beds are not laterally extensive enough to warrant mapping as distinct tongues. The pebbles and cobbles are composed of well-rounded, subspherical, red or brown Triassic siltstones and sandstones, and pinkish to gray Paleozoic or Precambrian vein quartz or quartzite, all set in a red sandstone matrix. Occasionally pinkish marble-textured limestone pebbles are present, but frequently they are dissolved, leaving a pitted surface. The pebbles occur in sandstones as local bands or lenses up to 30 feet (9 m) thick and disappear as individual horizons in a short distance laterally, but as an aggregate of horizons, they may persist for several thousand feet laterally.

The conglomerates are interpreted as alluvial* fan deposits (fanglomerates). They are restricted to the upper part of the Gettysburg Formation, and at the north margin they are among the youngest Triassic sediments deposited in the area. Three types of fanglomerates, distinguished on composition, are mapped. One type of fanglomerate is composed of poorly sorted, white to pinkish vein-quartz pebbles, cobbles, and boulders with minor amounts of red siltstone pebbles and cobbles in a poorly sorted, red silty sandstone matrix. A second type of fanglomerate is entirely composed of poorly sorted, fine-grained bluish limestone pebbles, cobbles, and locally boulders stained reddish and altered in places to finely crystalline marble in a poorly sorted matrix of red calcareous sandstone (Figure 13). The fragments are subrounded to subangular, etched, and poorly sorted. The third type of fanglomerate contains both poorly sorted limestone and quartz-siltstone fragments in a poorly sorted, reddish, locally calcareous, sandstone matrix.

Where intruded by diabase bodies the sediments are thermally metamorphosed for a distance of several hundred feet from the contact. The shales are baked to a tough, compact hornfels, usually bluish gray but occasionally cream colored with streaky color banding reflecting original composition. The sandstones alter to a gray quartzitic sandstone to quartzite with development of minor amounts of magnetite, pale-green augite, and traces of sphene, apatite, and zircon; where the sandstones are calcareous, secondary chlorite and epidote are present (Hotz, 1950). In the contact zones limestone fanglomerates are bleached to a white dense fine-grained to crystalline marble containing traces of augite and garnet.

Triassic rocks are unconformable upon Paleozoic or Precambrian rocks. The upper boundary is the present erosion surface or local Tertiary(?) high terrace gravels and Recent alluvium.

The thickness of the Gettysburg Formation from simple outcrop pattern appears to be about 15,000 feet (4,600 m), similar to the 15,500 feet (4,720 m) calculated by Stose and Jonas (1939) to the south. However, this writer's structural interpretation of the Gettysburg Basin includes a number of large normal antithetic faults, not shown on the geologic map

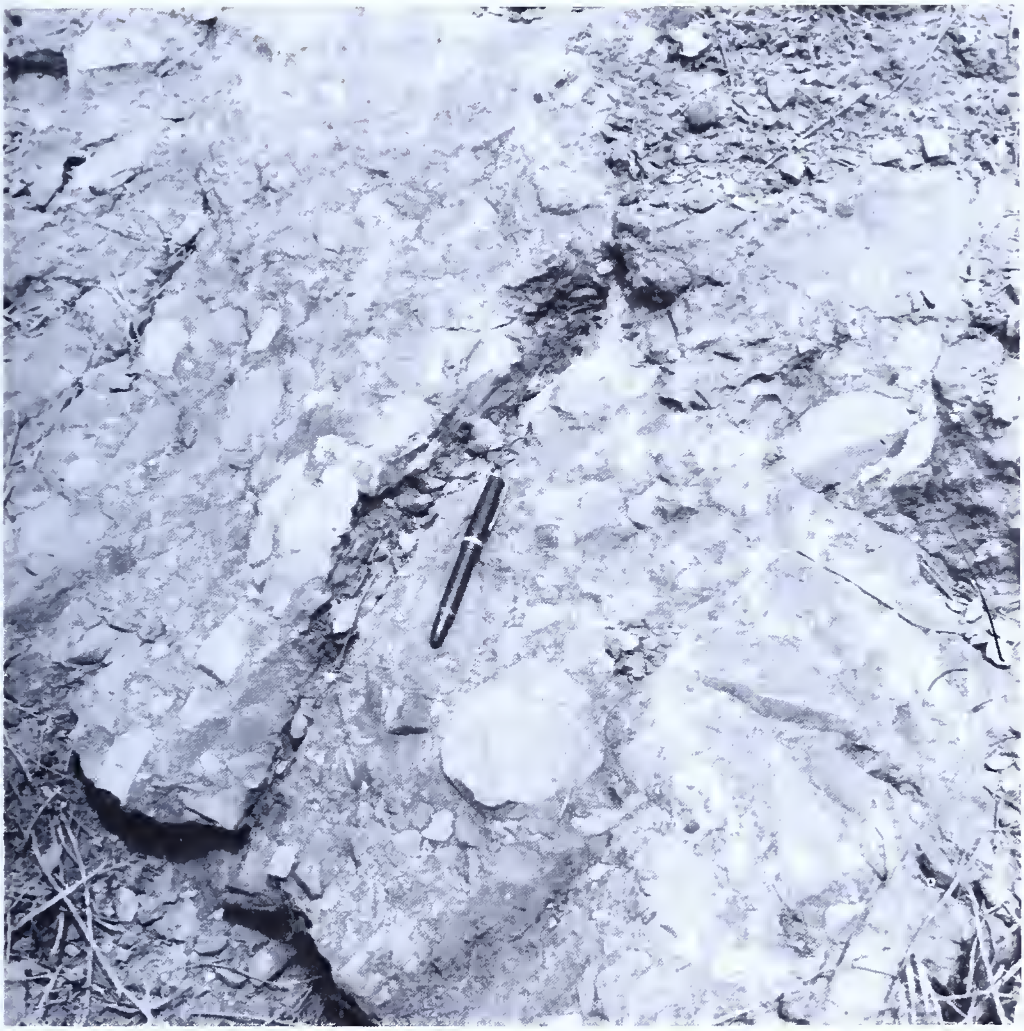


Figure 13. Triassic limestone fanglomerate at the north margin of the Gettysburg Basin near Bowmansdale. Pen gives scale.

(Plate 1), that repeat the stratigraphic section. Therefore, the actual thickness is considerably less than the values cited.

DEPOSITIONAL HISTORY

The depositional history of the Cambrian and Ordovician sediments from the Conococheague Group to the Martinsburg is set forth briefly in this section. The limited area of this report in relation to the Appalachian Basin and limited exposures permit only the general interpretation that miogeosynclinal sedimentation occurred principally in a stable, shallow, open-marine sea until the Middle Ordovician, when conditions were less stable and seas became deeper.

The carbonate beds of the Zullinger-St. Paul sequence were deposited in an environment probably somewhat similar to that of the present Bahama Banks platform. The seas were so shallow that slight movements of sea level could shift environments from shallow, open marine (detrital, oolitic, and intraformational conglomeratic sediments) to intertidal (stromatolitic and micritic sediments) or supratidal (algal-mat dolomites and "birdseye" micritic limestones).

Environmental conditions changed during the deposition of the Chambersburg Formation. The argillaceous composition and cobbly character of the limestones indicate the development of a paleoslope and conditions of marine water deeper than existed during the deposition of the older sediments. Metabentonite beds, which are a volcanic ash deposit, and probable slight unconformities within the formation are an indication of the beginning tectonic instability of the region. As the basin deepened and regional tectonism became more pronounced, the distal-turbidite sediments of the Martinsburg Formation were deposited. During deposition of the Martinsburg, bodies of allochthonous graywacke, limestones, red beds, and cherts were transported into the basin by gravity sliding, possibly in conjunction with thrusting. Although nearly continuous sedimentation persisted in the Appalachian Basin through the Ordovician into the Pennsylvanian Periods, the younger rocks have been eroded from the mapped area.

After the Alleghanian (late Paleozoic) deformation and uplift, Triassic sediments were deposited in piedmont-plain and coastal-mud-flat environments similar to deposits presently accumulating in the Colorado River delta and restricted Salton Sea. The fanglomerates, previously considered to be evidence of relief due to border faulting, may be debris-flow accumulations (Glaeser, 1971).

SURFICIAL DEPOSITS

Several types of surficial deposits are recognized in the mapped area. These include high terrace deposits of Tertiary(?) age, low terrace deposits of Quaternary age, Quaternary alluvium along major streams and rivers, and colluvial deposits at the base of Blue Mountain. These deposits were mapped in general terms, and a detailed study, similar to that of Pierce (1966), would define a considerable variety of surficial deposits of complex genesis. The soils of this area are described in the Cumberland County soil map (Farrel and others, 1956).

High Terrace Deposits

Extending over a limited belt (Plate 1) east of Lisburn, York County, is a high terrace deposit of probable Tertiary age. This deposit occurs at an elevation of 500 to 700 feet (152 to 213 m), but as Stose and Jonas (1939) recognized three terrace deposits at elevations of 720 to 740 feet (220 to 225 m), 600 to 640 feet (185 to 195 m), and 500 feet (150 m), it is possible that more than one terrace is actually present here. The lack of a well-developed topographic bench hinders resolution of this problem.

This terrace deposit is several feet thick and locally may be more than 10 feet (3 m) thick, generally thickening upslope. It is very poorly sorted and principally composed of locally derived Triassic sandstones and conglomerates that range up to boulders 14 inches (35 cm) in diameter. Minor amounts of Paleozoic quartzitic sandstone cobbles, secondarily stained red, up to 4 inches (10 cm) in diameter, and vein-quartz pebbles up to 2 inches (5 cm) in diameter are also present. The clasts are blocky to subspherical and subrounded and are set in a poorly indurated, red sandy silt-clay matrix.

Low Terrace Deposits

Four lower level Quaternary terrace deposits were mapped in York County by Stose and Jonas (1939). Only the highest of these deposits, at an elevation of about 580 to 420 feet (180 to 130 m), is mapped in this area. The lower ones are either not mapped or mapped as part of the Quaternary alluvium, so that the terrace deposits (Stose and Jonas, 1939) that locally underlie the site of the Capital City Airport are shown as alluvium. This was done because the lowest terrace deposits merge into alluvium, and it is difficult to discriminate between the two in urbanized areas. The Quaternary terrace deposit that was mapped consists of a thin, discontinuous veneer, only a few feet thick, principally along Yellow Breeches Creek. It is composed of pebbles and cobbles of Paleozoic quartzitic sandstones, vein quartz, and Triassic sandstones and siltstones. The clasts are subspherical, well rounded, and set in a poorly indurated matrix of red silt clay.

Quaternary Alluvium

The term alluvium is used here to include all detrital accumulations greater than 5 feet (1.5 m) thick deposited by modern rivers. Thus, it includes recent stream flood deposits in the area. Alluvium is easily mapped along the major streams and the Susquehanna River; however, some of the smaller streams in the Triassic terrain contain minor areas of alluvium that are included on the map (Plate 1) although they are not well defined and are quite thin. The alluvium consists of unconsolidated clays and silts and thick interbeds of fairly well sorted, well-rounded, subspherical to spherical material ranging in size from sand, in some of the smaller streams, to boulders along the Susquehanna River. The material in the smaller streams in the Triassic terrain is locally derived, consisting of fine fragments of mudstone and sandstone. Along the Susquehanna it is derived from various sources, some of which are many miles distant. In excess of 30 feet (9 m) of alluvium has been measured along the Susquehanna, but it is considerably thinner along the smaller creeks, especially away from major streams. Most of the alluvium mapped in the Triassic terrain is only slightly more than 5 feet (1.5 m) thick, as bedrock is nearly at the surface along most streams.

Colluvium

A belt of Quaternary/Recent (?) colluvium is mapped at the base of Blue Mountain. The deposit is thickest at the base of the mountain and thins progressively toward the crest of the mountain. Only colluvial cover greater than 5 feet (1.5 m) in thickness is shown on the map. Excavations made at the base of the deposit during construction of the Interstate 81 interchange show as much as 40 feet (12 m) of colluvium; upslope it is only a few feet thick. The colluvium is derived from quartzitic sandstones and conglomerates of the Bald Eagle, Juniata, and Tuscarora Formations that form Blue Mountain. It consists of poorly sorted, angular blocks of this material in a matrix of sandy clay-silt. Apparently the colluvial mass is at static equilibrium because there is no evidence of historic movement of material.

TRIASSIC DIABASE

by

Robert C. Smith, II

INTRODUCTION

The Triassic diabase in the northern half of the New Cumberland quadrangle consists of two of the types described by Smith and others (1975): 1) the older, York Haven type, which contains approximately 1.1 percent $Ti0_2$ in chilled margins and forms all of the sheets and one half of the dikes in the mapped area; and 2) the Rossville type, which contains 0.7 percent $Ti0_2$ in the chilled margins and forms two dikes in the mapped area. One of these dikes extends from Goldsboro to 0.5 mile (0.8 km) north of Newberrytown (Goldsboro dike). The second dike extends from a point 0.65 mile (1.05 km) northeast of Wickersham Hill to a point 1.7 miles (2.7 km) west-southwest of Sassafras Island (Yocumtown dike).

The composition and petrography of the diabases is summarized in Tables 1 and 2 (from Smith, 1973).

Table 1. *Median Composition of Diabase Chilled-Margin Samples from Pennsylvania*

(Oxides are reported in percent. See Smith (1973) for additional analyses.)

	York Haven	*Rossville*
SiO_2	51.8	50.6
Al_2O_3	14.3	16.6
Fe_2O_3	1.2	1.1
FeO	8.8	9.0
MgO	7.7	6.8
CaO	10.7	10.8
Na_2O	2.0	2.0
K_2O	.6	.4
TiO_2	1.1	.7

Table 2. *Typical Modal Mineralogy of Chilled-Margin (Fine-Grained) Samples of York Haven and Rossville Types of Diabase*

(See Smith (1973) for a description of accessory, sulfide, and oxide minerals.)

	York Haven	*Rossville*
Felsic minerals	Groundmass plagioclase laths approximately An_{60}.	Groundmass plagioclase laths approximately An_{60}. Centimeter-sized phenocrysts approximately An_{90}.
Mafic minerals	Approximately 1% (euhedral) olivine microphenocrysts. Common augite microphenocrysts. Sparse hypersthene phenocrysts. Pigeonite groundmass.	Approximately 1% olivine microphenocrysts. Augite with either hypersthene or pigeonite makes up groundmass pyroxene.

THE YORK HAVEN DIABASE SHEET
(Gettysburg and York Haven Plutons)

The western third of the York Haven diabase sheet is exposed in the mapped area. The diabase along the Susquehanna River between York Haven and Falmouth is the type locality for the York Haven diabase (Smith, 1973). At the York Haven type section, this diabase sheet is approximately 2,500 feet (760 m) thick. The lower contact of the York Haven sheet at the concordant southern limb (at York Haven) dips 40° to the north, whereas the upper contact of the discordant northern limb (along Interstate 83 at Reesers Summit) dips 35° to 40° to the south.

Except for the volatile (H_2O, Cl, S, etc.) content and the fact that it is slightly more reduced, the magma of the York Haven sheet was similar to that of the York Haven type elsewhere. The only Cornwall-type deposits known in the northern half of the New Cumberland quadrangle are the small occurrences near Grantham (Rose, 1972).

ECONOMIC GEOLOGY AND LAND USE IMPLICATIONS OF DIABASE

As elsewhere in southeastern Pennsylvania, the presence of diabase has determined land use. In the past, areas of diabase were disdained because the minimal soil is nearly impossible to farm. More recently, areas of diabase have received some favor as housing sites because of the higher elevation and uncut trees; however, there are serious problems of low water well yields, expensive excavation costs due to the need for intensive blasting and use of heavy machinery, and major problems with on-lot sewage disposal.

Copper mineralization occurs along the York Haven-type diabase contacts north-northeast of Lisburn (40°11′08″N/76°54′22″W), and scattered hematite occurs in the area north to east of Frogtown (Stose and Jonas, 1939, p. 131-132). Neither of these mineral occurrences appears to offer any significant possibility for a major economic mineral concentration.

STRUCTURAL GEOLOGY

INTRODUCTION

The mapped area is naturally divisible into three structural units, each characterized by a unique and fundamentally different structural style. These belts, from north to south, are the South Mountain anticlinorium, which includes rocks of the Cumberland Valley sequence; the Yellow Breeches thrust sheet, which includes rocks of the Lebanon Valley sequence; and the Triassic monocline. Structure of the South Mountain fold in Franklin County has been described by Root (1968, 1970, and 1971). Structure and stratigraphy of the Martinsburg Formation in part of Cumberland County has been described by Dyson (1967) and in Dauphin County by Carswell and others (1968) and Platt and others (1972). In Dauphin County structure of the Yellow Breeches thrust sheet is described by MacLachlan and Root (1966) and MacLachlan (1967). Structure of the Gettysburg Basin is described in detail by Bissell (1921) and Stose (1932, 1949, 1953), and in general terms by Faill (1973).

Briefly, two sequences of Cambro-Ordovician sedimentary rocks are present, separated by the Yellow Breeches thrust (Plate 1). North of the thrust the rocks are part of the autochthonous Cumberland Valley stratigraphic sequence, which extends southwest along the Great Valley into Maryland and Virginia with a general lithologic uniformity. These rocks were deformed in the late Paleozoic Alleghanian orogeny (D_2) and constitute part of the larger South Mountain anticlinorium and deformation plan described by Cloos (1947). The terrain is characterized by gently eastward plunging asymmetrical folds with subvertical to overturned north-facing anticlinal limbs. Axial planes of folds dip southeast, and the well-developed South Mountain cleavage (S_2 in this area) lies parallel to them , fans about fold hinges*, and also dips southeast. Several steep thrusts, developed late in the folding and probably dipping 60° southeast, parallel the fold traces.

Cambro-Ordovician rocks south of the Yellow Breeches thrust are part of the allochthonous Lebanon Valley stratigraphic sequence (MacLachlan and Root, 1966, and MacLachlan, 1967), which has affinity with the Conestoga Valley section of the Piedmont province. These rocks are part of a series of nappes probably generated during the Ordovician Taconic orogeny (D_1). Inversion of the stratigraphic section and development of a cleavage (S_1) occurred at this time. Shortly after Alleghanian deformation of the Cumberland Valley sequence into the South Mountain anticlinorium, the rocks of the Lebanon Valley sequence (D_1) were thrust along the Yellow Breeches fault (D_3) from the southeast into their present location upon the Cumberland Valley sequence. This thrust dips very gently to the southeast and even to the northwest locally (MacLachlan, 1967). Movement on the thrust impressed a tectonite fabric, including latest cleavage (S_3) and reoriented and syngenetic folds ($B \perp B'$), in the rocks of both sequences adjacent to the thrust. Movement of the Yellow Breeches thrust is considered to be latest Alleghanian (D_3).

This terrain was then eroded to form the geologically complex surface that constitutes the Paleozoic basement upon which nonmarine Triassic red sediments were deposited. Then the Triassic Basin was rotated regionally and disrupted by development of antithetic normal faults, so that strata now dip to the west and northwest (D_4). A series of diabase sheets intruded these sedimentary rocks, but the time of emplacement relative to rotation is still uncertain.

A synopsis of terms used in this discussion is presented in Table 3.

SOUTH MOUNTAIN ANTICLINORIUM

Between the Yellow Breeches thrust and the Ordovician-Silurian clastics that form Blue Mountain are rocks of the Cumberland Valley stratigraphic sequence which are folded into the South Mountain anticlinorium. Because several formations can be mapped within the belt of carbonate rocks, their structure is more decipherable than that of the Martinsburg Formation. Although these rocks have been deformed together (D_2), for discussion purposes they are divided into separate sections.

Table 3. *Structural Elements in the Harrisburg West Area*

Age	Deformation	Penetrative surface*	A-lineation	Folds	B-lineation	Location
Ordovician (?)	D_1	S_1 (tectonite)	A_1	F_1 (nappe)	B_1 (S_0xS_1)	Yellow Breeches thrust plate and klippe. Mixed terrain in some rocks.
Terminal Paleozoic (Early Alleghanian)	D_2	S_2	A_2	F_2	B_2 (S_0xS_2)	South Mountain anticlinorium.
Terminal Paleozoic (Late Alleghanian)	D_3	S_3 (locally tectonite)	A_3	F_3 (incl. $B \perp B'$ reclined and upright folds)	B_3 (S_0xS_3)	Immediately above and below Yellow Breeches thrust.
Late Triassic-Early Jurassic	D_4	—	—	—	—	Triassic Basin; also local normal faulting and regional rotation of Paleozoic basement to NW.

*S_0 = primary bedding in rocks of all ages.

Structure in the Carbonate Rocks

Faults

The geologic map (Plate 1) presents a complex pattern of folds and faults. Based on truncation of one set of structures by another set, one might postulate a sequence of structural events. However, any sequence established would only be of local significance as all complexities may be accounted for by horizontal shortening during a single early Alleghanian (D_2) orogeny in which south-dipping high-angle thrust fault segments, in shearing upward into younger stratigraphic units, truncate folds and derived faults. The best example of such relationships is the Reading Banks fault, a major fault in the Mechanicsburg quadrangle, which enters the area on the west near Windsor Park and splits into the Cedar Cliff and Camp Hill faults. In splitting, a presumably subvertical fault segment is developed normal to the structural grain, truncating the large Mechanicsburg anticline. In nearly all cases the faults develop in the north-facing anticlinal limbs, a relationship established in the same belt of rocks to the southwest (Root, 1973) and believed to indicate that faulting developed after the folds were initiated. Only the Lemo and Paxtang faults are exceptions to this structural position, but they still are considered to be steep south-dipping thrusts.

All major faults in the carbonate rocks are subparallel to the structural grain and classed as steep thrusts dipping about 50° to 60° south (Root, 1970). Displacement across the faults is considerable. For example, the Cedar Cliff fault on the west juxtaposes Shadygrove beds against Pinesburg Station beds—a stratigraphic separation of about 3,000 feet (900 m) and an estimated throw of 10,000 feet (3,000 m). Displacement across this fault apparently decreases eastward. The fault transects the north limb and hinge of the Windsor Park anticline at the Susquehanna River, and St. Paul beds are in fault contact, with an apparent displacement of less than half of that on the west. Actually, total shortening adjacent to the fault is probably of the same order here as on the west because fault displacement here is transferred to folding beneath the thrust. On the west there is considerably less folding beneath this thrust.

The Camp Hill fault thrusts St. Paul beds against Martinsburg beds—a moderate stratigraphic separation. However, the displacement is probably considerable because Martinsburg beds at the fault are principally within the main body of the Martinsburg. Similarly, the Lemo fault thrusts the Chambersburg over the Martinsburg with an apparently small displacement, but, as the beds are stratigraphically high in the Martinsburg sequence, the displacement is considerable. In both instances the Martinsburg is highly folded at the fault, indicating considerably more total shortening than the apparent stratigraphic displacement might suggest.

Folds

Faulting is so intense that single folds have only limited lateral extent. The Windsor Park anticline, which is the largest fold, has a clearly defined axis extending 3.0 miles (4.8 km) between Windsor Park and White Hill, where it is truncated by the Cedar Cliff fault. Exposed portions of the upper plate of this fault, however, probably lie in the south limb of the anticline. The Hoover School anticline extends across half of the carbonate belt, but it is limited by the tear fault segments of the Camp Hill fault. On the west, plunging noses of two large folds—the Mechanicsburg and Salem Church anticlines—extend across much of the Mechanicsburg quadrangle. The Mechanicsburg anticline is on trend with the Windsor Park anticline, but these are distinct structures separated by the Reading Banks-Camp Hill faults.

As noted previously, the folds are asymmetrical, with subvertical to overturned north-facing anticlinal limbs and upright south-facing anticlinal limbs dipping south at 30° to 45°. Axial surfaces dip steeply south. A pi diagram* of the area between the Yellow Breeches thrust and Cedar Cliff fault indicates that the Windsor Park anticline plunges 080/12° (Figure 14). A pi diagram of the area between the Camp Hill and Cedar Cliff faults indicates that the Hoover School anticline plunges 082/7° (Figure 15). In both diagrams there is considerable scatter about the best great-circle* fit, which may reflect reorientation of these early Alleghanian folds by late Alleghanian movement (D_3) of the Yellow Breeches thrust sheet over these rocks. A pi diagram of the Salem Church anticline (Figure 16) shows similar fold orientation (076/16°) but better fit of the great circle, suggesting lesser subsequent reorientation.

Cleavage (S_2)

Cleavage present in these rocks is principally the South Mountain cleavage (S_2) formed during the early Alleghanian folding (D_2) and described by Cloos (1947). Regionally cleavage parallels the folds, fans about the fold hinge, and dips southeast. The cleavage is weakly developed on the north and prominent on the south, reflecting a regional increase of stress in this direction. Within an individual fold, cleavage is more intense in the overturned limb than the upright limb.

Cleavage (S_3)

A later cleavage, S_3, has locally been imposed upon these rocks by thrusting of the Yellow Breeches plate (D_3) across the South Mountain anticlinorium. Rocks of the South Mountain structure (D_2), immediately below the Yellow Breeches thrust sheet, dip moderately south, and bedding and preexisting cleavage have been transposed into the S_3 movement surface. This is shown to advantage in rocks of the St. Paul Group in the

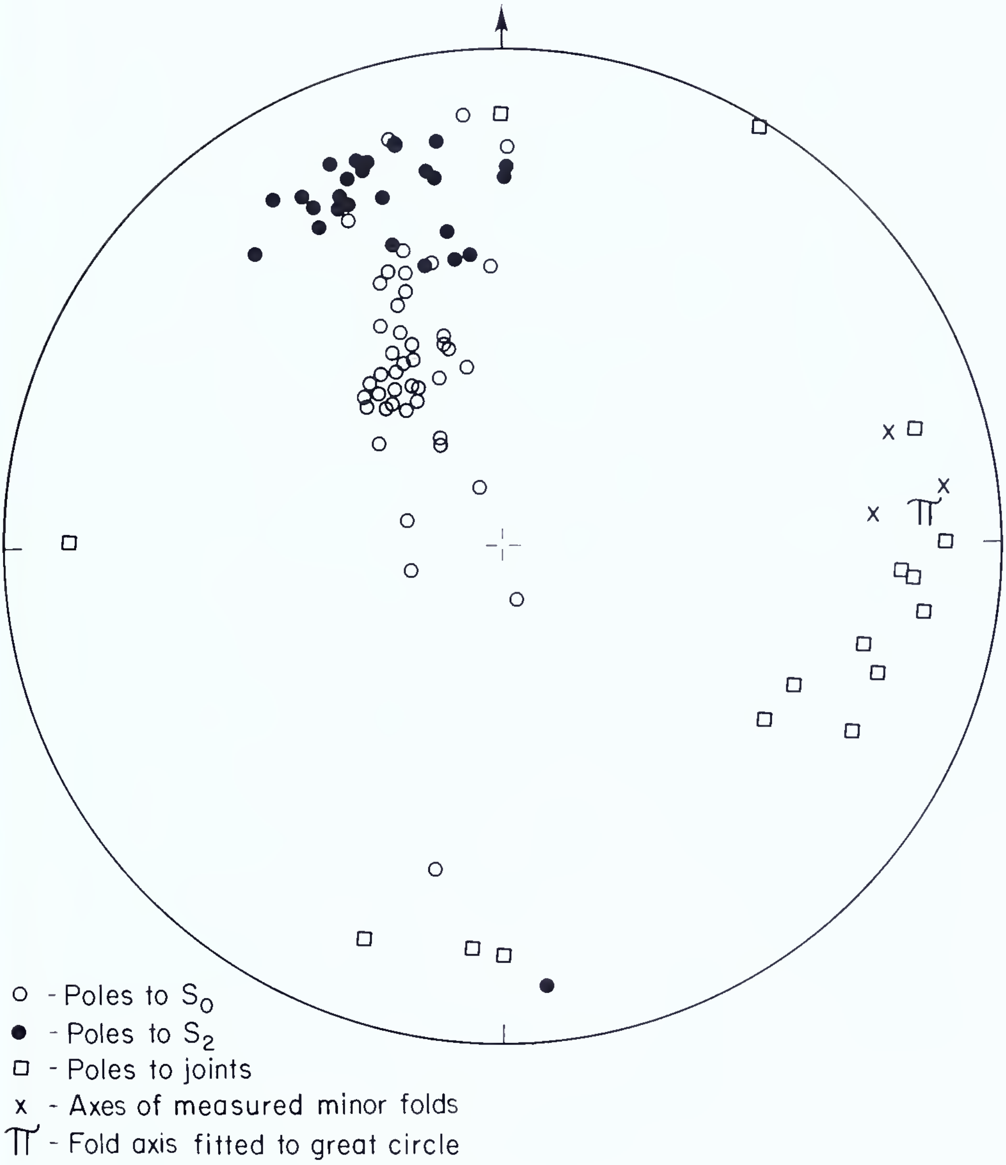


Figure 14. Pi diagram and joint poles from the Windsor Park anticline, South Mountain anticlinorium.

Hempt Bros. quarry about 500 feet (150 m) north of the leading edge of the thrust. Development of S_3 here is intense, with megascopically penetrative S_3 spaced about 10 to 20 mm, and southeast-plunging streaking lineations, geometrically similar to those in the overriding Yellow Breeches sheet. There is an intense development of flow folds, at a microscopic and mesoscopic* scale (Figure 17), approaching a $B \perp B'$* reclined geometry, although these folds are not syngenetic but reoriented. Dolomite interbeds are boudinaged*, with the principal necking direction*

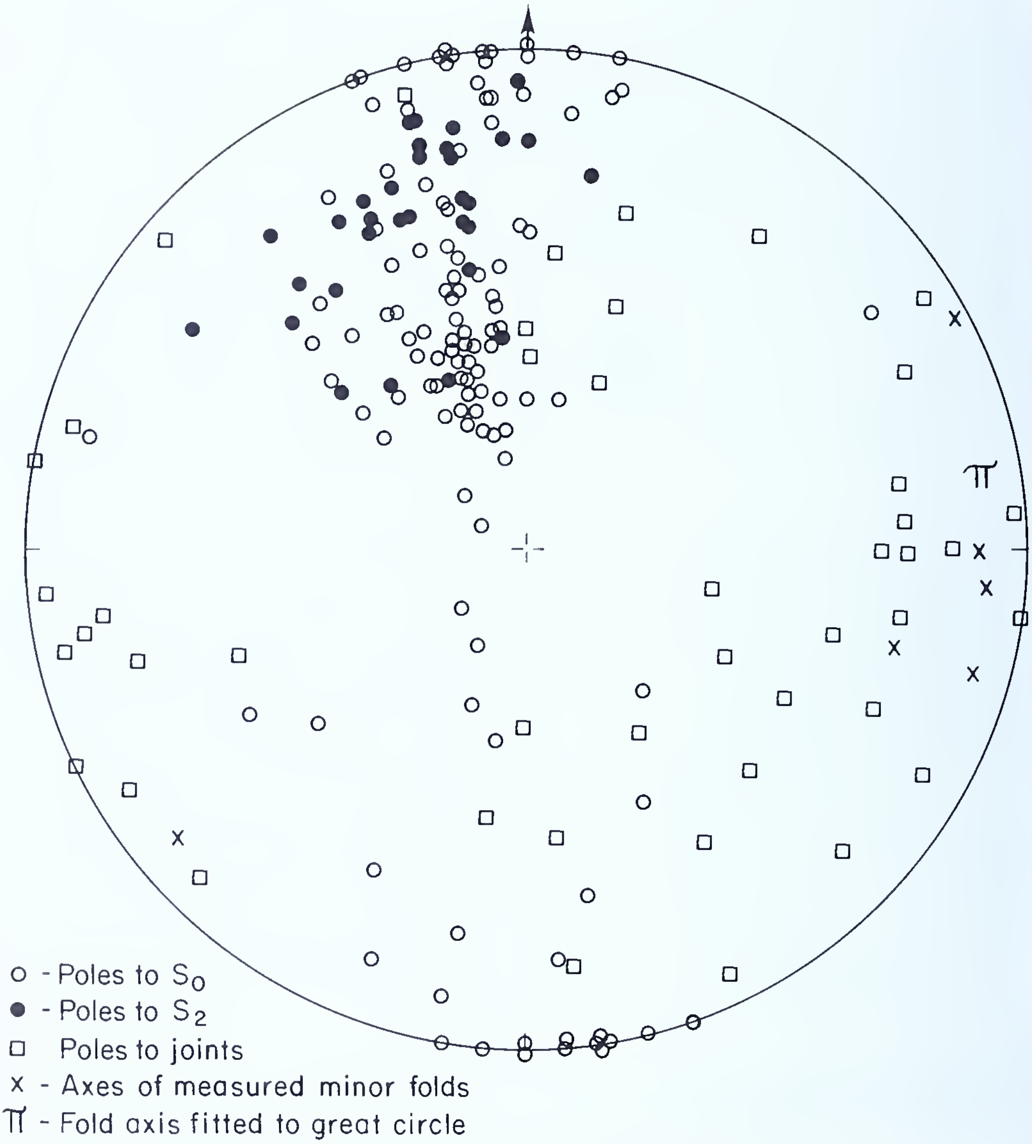

π
○ - Poles to S_0
● - Poles to S_2
□ Poles to joints
x - Axes of measured minor folds
π - Fold axis fitted to great circle

Figure 15. Pi diagram and joint poles from the Hoover School anticline, South Mountain anticlinorium.

about normal to streaking lineation* A secondary minor necking direction is about parallel to the streaking lineation.

Development of S_3 is not uniform adjacent to the Yellow Breeches thrust. At the west end of the area at Winding Hill, beds in the Rockdale Run Formation carry principally the S_2 cleavage, and what appears to be possibly a weakly developed S_3 is subordinate and at a moderate angle to bedding. It may be that what are considered as S_3 surfaces are actually S_2 planes that have been used as slip surfaces and reoriented during D_3.

S_3 is developed in the South Mountain carbonate rocks as much as 3,000 feet (900 m) north of the Yellow Breeches thrust. St. Paul beds

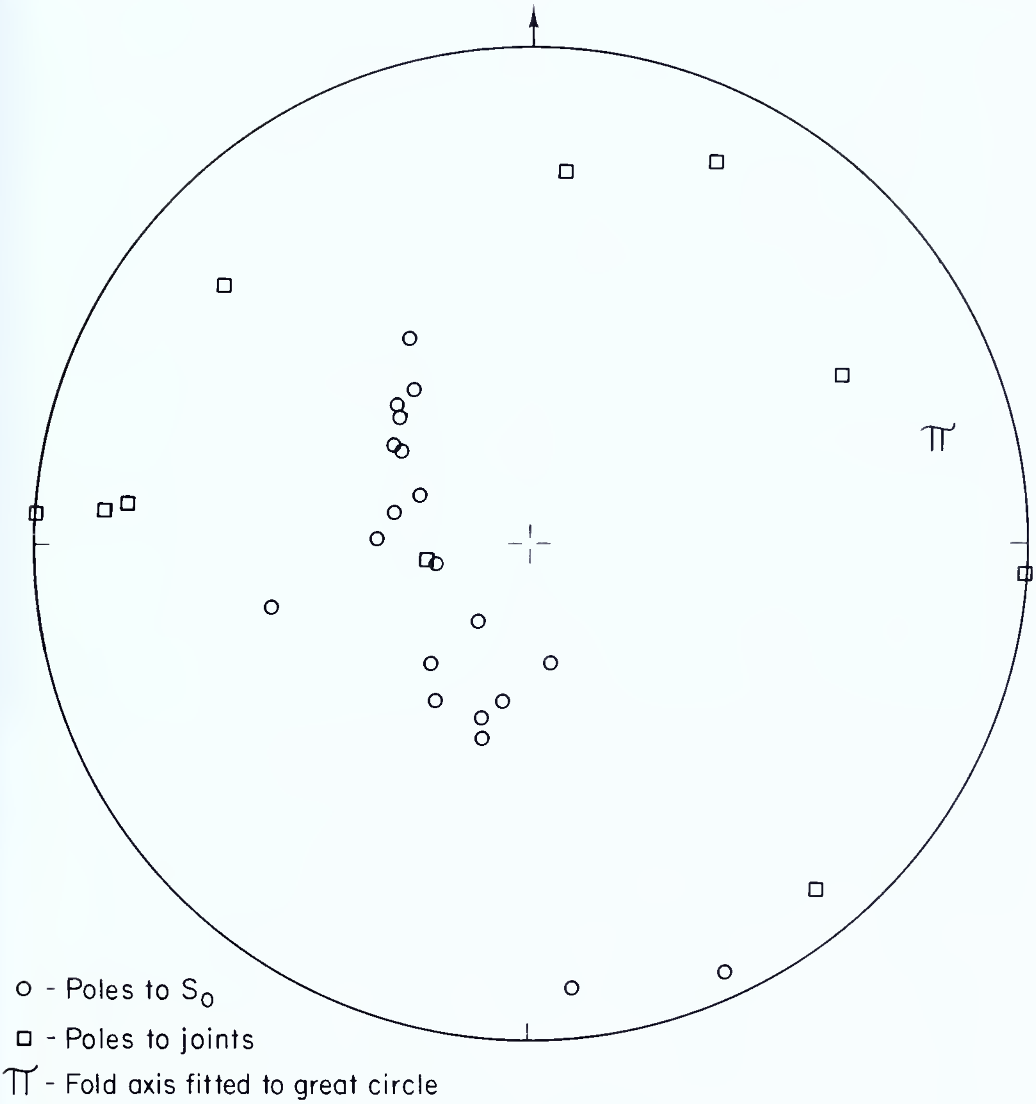


Figure 16. Pi diagram and joint poles from carbonate rocks of the Salem Church anticline, South Mountain anticlinorium.

near Manor School, New Cumberland, bear an S_0 transposed partly or wholly to S_3 and occasionally streaking lineations which plunge southeast. Striping, due to the intersection at small angles of S_0 and what is either reoriented S_2 or primary S_3, is also present this far north.

To the west S_3 extends only a few hundred feet beyond the Yellow Breeches thrust. For example, at Winding Hill there is no visible S_3 except close to the fault. However, the effects of D_3 (late Alleghanian) deformation, which produced S_3, extend considerably beyond its immediately visible effects, for girdles of pi diagrams are somewhat diffuse, indicative of D_3 reorientation.

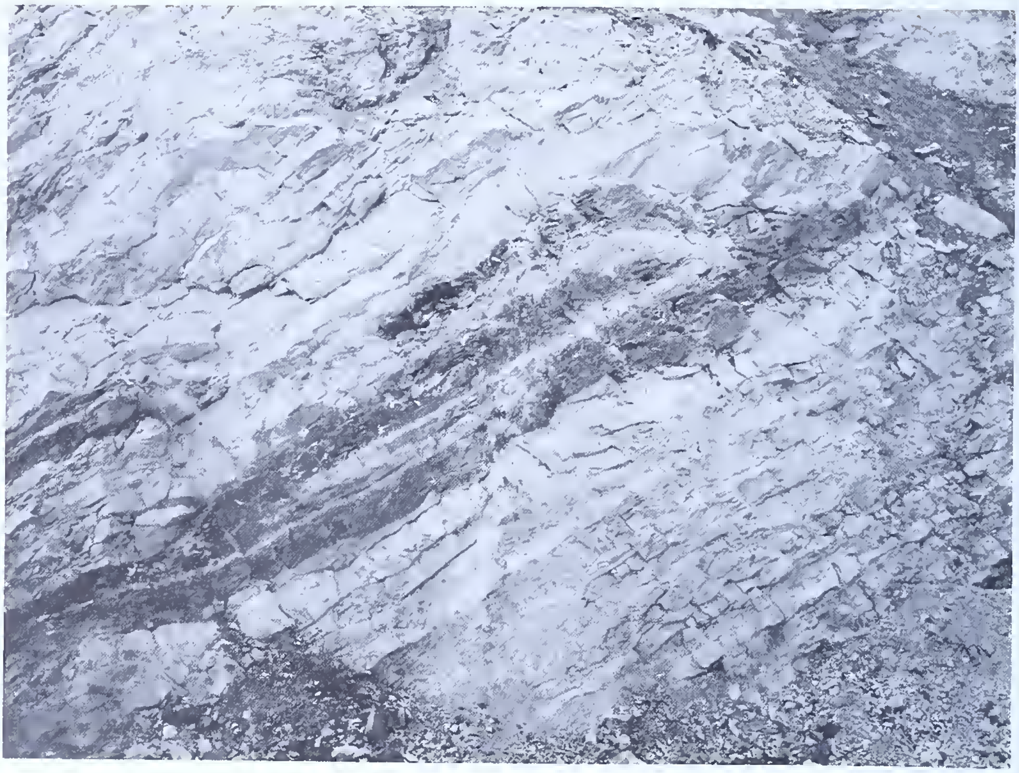


Figure 17. Reclined $B \perp B'$ fold developed in limestones during Yellow Breeches thrusting (D_3), Hempt Bros. quarry, Lower Allen Township. Fold shown by thin white bed surrounded by thicker dark-gray beds. Distance between fold limbs is about 5 feet (1.5 m).

Joints

Joints are considered in this report for their local importance in engineering and environmental geology. Their use in deciphering tectonic history in such a complex terrain is limited. A large number of joint data were collected from the carbonate rocks.

Joints in the carbonate terrain were examined regionally by Cloos (1947, p. 898-900). He recognized tension joints both normal to fold axes and to lineations, as well as joint systems that are acutely bisected by either the fold axis or lineation in *a**. Thus there are six major joint directions, and each may show secondary and small fractures as associated feather joints. Tension joints, normal to the fold axes, are largely vertical or dip steeply, strike northwest, tilt in response to plunge of the folds, and are very common. Tension joints, parallel to the strike of axes, dip northwestward about normal to lineation. Joint systems or shear joints commonly intersect at about 60° in sets both parallel and normal to the fold axes. It was concluded that the joints formed slightly later in time than ooid extension and in the same tectonic deformation plan.

Joint data on the Windsor Park anticline (Figure 14) indicate a concentration of subvertical joints defining an east-west and north-south system, which may be related to South Mountain folding (D_2), representing one tension set parallel and another tension set normal to the fold axis (F_2). Data from the Hoover School anticline (Figure 15) show greater joint scatter, which possibly reflects a subvertical tension system parallel and normal to F_2 and a later set, dipping northwest, attributable to Yellow Breeches movement (D_3). However, this explanation is partly unsatisfactory, as this later joint set is not present on the Windsor Park fold, which is nearer to the Yellow Breeches thrust and should bear greater impress of D_3-related joints. Joint data from the Salem Church anticline (Figure 16) are too sparse to yield conclusions.

Spacing of joints in the limestone is on the order of one to several feet, although locally spacing is closer. Typically, separation across these joints is about ⅛ inch (32 mm), and they are usually calcite filled. Due to solution the calcite filling is frequently dissolved, and fissure development occurs along the joints. In the limestones joints exert considerable hydrologic control and are important for development of quarry faces.

The Pinesburg Station Formation contains the only appreciable thickness of dolomite. In other units dolomite occurs only as discrete massive interbeds. Dolomite, which is brittle in comparison to the limestone, has both more joint sets and a close spacing (several inches). However, the joints do not appear to be effective, either for hydrologic control in that they are not enlarged by secondary solution, or for quarrying in that they are not as through-going as joints in the limestone, and the numerous sets impede development of a discrete quarry face.

Fracture Traces

Fracture traces*, recognized by topographic and tonal expressions on air photos, are present in the carbonate rocks, but they were not studied systematically and are not mapped. A local study near Windsor Park shows observed fracture traces parallel to three joint systems and the S_2 mapped in this area. The traces are presumably controlled by these structures.

Study of fracture traces, for hydrologic or other purposes, is difficult in a heavily urbanized area such as this. Fracture traces that are related to some mapped structural element are undoubted geologic features, whereas those that are unrelated should be suspect as they may be merely subtle man-made features.

Structure in the Martinsburg Formation

Because of a lack of persistent identifiable beds or units of convenient scale, it is extremely difficult to decipher large-scale structure of the

Martinsburg Formation. Selected exposures illustrate a variety of complex details which can be reconciled with a large-scale model only in a general way. S_2 cleavage is pervasive, and there is significant transposition of bedding into parallelism with this cleavage, with the result that bedding orientation may be obscure or misleading. Allochthonous elements within the Martinsburg terrain are further complicated by the presence of an older cleavage, S_1, often associated with isoclinal folds that have been refolded by the South Mountain deformation (D_2). Interpretation of structures associated with the allochthonous elements is further complicated by uncertainty as to whether present boundaries represent redepositional limits of such elements or subsequent faulting. All of these structures may be reoriented to varying degrees, with an intensity that apparently increases northeastward. Movements producing this reorientation are evidently parallel to the emplacement of the Yellow Breeches thrust plate and are probably related to the D_3 (late Alleghanian) episode.

Faults

A myriad of small faults are present within individual lithologic units, but the only clearly demonstrable fault that juxtaposes different lithic units is in the railroad yards at Enola, where grayish and greenish hackly mudstones are thrust, on a steeply south dipping D_2 (?) fault, over limestone conglomerates. Poor exposure prevents local determination of the extent and significance of this fault, but it is aligned with a major fault in Dauphin County (Carswell and others, 1968). It may be that many contacts between the various lithologic units are faults, but exposures are lacking to confirm this. Considering the structural complexity within the Martinsburg and the large number of small faults observed at outcrops, it is expected that considerable major faulting occurs. Three large faults, mapped in the carbonate rocks of the Mechanicsburg quadrangle, extend into the Martinsburg belt. They are shown on the geologic map to form the boundary between different lithologic units, but their location and presence in the Harrisburg area is problematical.

Several lines of indirect evidence indicate that an area centered about the confluence of Conodoguinet Creek and the Susquehanna River is a klippe of the Yellow Breeches thrust sheet. The occurrence of a sequence of thick, massive graywackes only in this area may be considered as stratigraphic evidence of this klippe. The presence of reoriented folds, described in the following section, of a type typically developed at the sole of thrust sheets, is evidence of major thrusting in this area. Small-scale subhorizontal thrusting occurring only in this area, described in the following paragraph, supports this interpretation. Structural evidence alone is ambiguous, as these features could develop immediately below the sole of a major thrust. However, the areally restricted, unique graywackes favor localization above a thrust as a klippe form. The graywacke beds in this klippe become steeply dipping at their northern limit, and it is inferred that this is caused by drag along a south-dipping normal fault, analogous to the Allendale fault on the main Yellow Breeches thrust sheet. The klippe is a partially downdropped segment of a much more extensive Yellow Breeches thrust sheet which has been eroded.

A number of small faults that resemble the reverse-faulting system in the Devonian Montebello north of Harrisburg (Cloos and Broedel, 1943) occur in cuts of the Penn Central Railroad at Conodoguinet Creek (Appendix 3-A). However, measurement of slickensides on these surfaces suggests that only part of this minor thrust development is attributable to the mechanism identified by Cloos and Broedel.

Folds and Cleavage

Despite intense local folding, only one major fold is identified with assurance in the area. A digitate band of basal Martinsburg limestone extends along the projected axis of the Salem Church anticline—a fold well defined by the older carbonate rock sequence. These basal Martinsburg beds do not define a fold with the same interlimb angle* (70°) as in the underlying carbonate rocks. Rather, the less competent Martinsburg beds are nearly reoriented into cleavage (S_2), so that minor folds are virtually isoclinal with a steeply dipping axial surface parallel to S_2 (Figure 8). In gross aspect, without primary bedding indicators or minor folds and fold hinges to indicate structural style, this belt could be interpreted as a series of steeply southeastward dipping beds, rather than a fold.

Similarly, the belt of allochthonous red beds and thin platy limestones may represent a partially faulted, nearly isoclinal fold. These form two discontinuous belts of steeply to subvertically south dipping strata, which may represent the two limbs duplicated by such a fold. To the west, in the New Bloomfield area, Dyson (1967) interprets these to be multiple discrete folded horizons, rather than a single horizon repeated in the limbs of a major fold. However, the evidence here is not conclusive, and these may merely be subsidiary folds on a major fold limb. Again, considering the obvious structural complexities and probable allochthonous nature of these units, these problems cannot be resolved with data presently available.

Structural analysis of folds and cleavage in the Martinsburg terrain (Appendix 3-B) demonstrates increasing complexity of deformation from wholly autochthonous rocks on the west to wholly allochthonous rocks on the east:

1). Folds in autochthonous Martinsburg, west of Carlisle, have interlimb angles of 90-130°, plunge 066/16°, show a kink-band* geometry with a well-defined pi-diagram girdle, and contain only S_2 cleavage.

2). Folds in autochthonous basal limestones of the Martinsburg, in proximity to the Yellow Breeches sheet, have interlimb angles of less than 60° to locally nearly isoclinal, plunge 092/32°, define a diffuse pi-diagram girdle that probably reflects limited reorientation effects of Yellow Breeches thrusting (D_3), and contain a single cleavage (S_2) which probably also served as a later (D_3) slip surface (S_3).

3). Allochthonous rocks in the mapped area contain both Taconic (D_1) and early Alleghanian (South Mountain D_2) folds and cleavage. The former occur as isolated isoclinal hinges showing local flowage, and cleavage (S_1). These are transected, sometimes at a large angle, by the dominant steeply southeasterly inclined South Mountain cleavage (S_2) and are locally transposed towards this cleavage. The latter folds, superimposed on the Taconic fabric, approximate typical South Mountain structures.

4). Allochthonous graywackes on the Yellow Breeches klippe show, in addition to the deformational fabric described above, other elements due to subsequent Yellow Breeches thrusting (D_3). The net effect has been to reorient the earlier folds into reclined folds that plunge down the S_2 cleavage, which was reactivated to be the S_3 slip surface during D_3 deformation.

Joints

Joints are extensively developed in the Martinsburg Formation. Within the pelitic units joints are spaced at several inches, but in the more competent graywacke and limestone units they are spaced at one to several feet. Generally the joints are open, but in the limestone and calcareous sandstones they may be calcite filled.

Distribution of the joints (Figure 18) forms a complex pattern and undoubtedly reflects the multiple deformation of these rocks. It has not been possible to relate the various joint sets to their respective generating deformations.

YELLOW BREECHES THRUST SHEET

In area this is the smallest structural unit mapped in the Harrisburg West area but is probably the most structurally complex. As noted previously, these rocks are part of the inverted limb of a regional nappe* series that becomes more extensive to the northeast, where it is part of the Reading Prong and its associated structure. These rocks, within the mapped area, represent the southernmost extension of the nappe series.

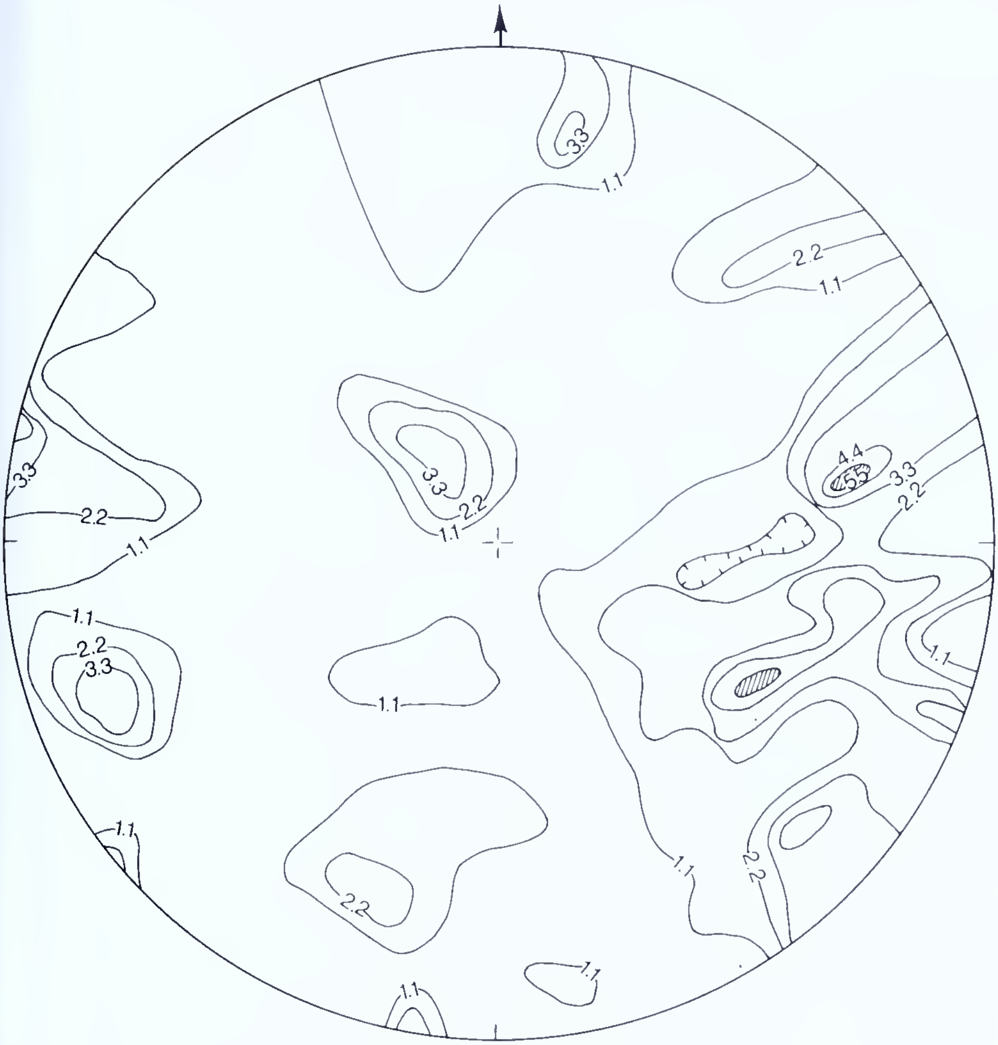


Figure 18. Joint pole diagram of the Martinsburg Formation on the South Mountain anticlinorium; N = 90.

Farther southwest rocks of this nappe series have been removed by erosion; however, it is believed that originally they did not extend in this direction any considerable distance beyond present limits.

Many of the data necessary to resolve the sequence of structural events on the Yellow Breeches thrust sheet are not available in the mapped area because of limited extent of the thrust sheet. The principal problems are to determine age of nappe formation and recognize its associated structural features, and determine the age of thrusting on the Yellow Breeches fault and recognize its associated structural features.

The latter problem can be resolved within the mapped area. Yellow Breeches thrusting is clearly later than development of South Mountain structures because it truncates these intensely folded and faulted structures, progressively overriding older rocks from east to west along a substantially undeformed subhorizontal thrust. The thrust sheet overrides Martinsburg rocks in eastern Dauphin County (MacLachlan, 1967) and overrides St. Paul to Conococheague rocks in the report area (Plate 1), and the erosional edge in the Mechanicsburg area overrides Middle Cambrian beds (Stose, 1953). Also, locally S_3 cleavage and F_3 folds are developed beneath the thrust in the underlying South Mountain carbonate rocks, features uniquely related to and bearing the impress of this thrusting. The Yellow Breeches thrust sheet is not merely the limb of a major late South Mountain overfold, because the stratigraphy on the thrust sheet differs so markedly from the stratigraphy of the overriden rock that clearly different basinal sequences are juxtaposed across the fault. On the above evidence it is concluded that thrusting on the Yellow Breeches fault is post-South Mountain (D_2—early Alleghanian) folding, and Triassic overlap of the thrust sheet indicates that thrusting preceded Triassic deposition. For these reasons movement of the Yellow Breeches fault is considered to be a late Alleghanian (D_3) event.

Determination of the time of nappe formation is ambiguous in the Harrisburg West area. From evidence here it might be considered that Yellow Breeches thrusting was the final stage of nappe formation and that therefore the nappes are of late Alleghanian age. However, in Dauphin County, MacLachlan and Root (1966) and MacLachlan (1967) concluded that the nappes are considerably earlier than, and refolded by, South Mountain folding. An Ordovician "Taconic" age of nappe formation is proposed here and along strike in crystalline-cored nappes northeast of Reading (Drake, 1970). Accepting an Ordovician "Taconic" age of nappe emplacement (D_1) and a subsequent late Alleghanian (D_3—terminal Paleozoic) age for thrusting of the nappes along the Yellow Breeches fault, it remains to assign cleavages, lineations, and minor folds to disparate tectonic events.

Faults

The major fault in this structural unit is the Yellow Breeches fault. It is demonstrably a very low angle thrust generally dipping southeast at only a few degrees; however, in Dauphin County MacLachlan (1967) maps this fault locally to be gently inclined to the northwest with fensters eroded through the thrust sheet. In the mapped area near Greenlane Farms, dip on the thrust plane is calculated to be about 3° to 5° southeast. From topographic expression of the thrust in the Mechanicsburg area, where it is eroded to a north-south-trending contact, the thrust appears to be subhorizontal.

Within the thrust sheet unnamed faults separate the carbonate rocks from shales of the Martinsburg Formation. These are considered as thrusts developed during nappe formation (D_1) and dip southeast at moderate angles (20° to 30°) approximately parallel to bedding-cleavage; however, a D_3 origin or reactivation cannot be excluded.

At Bowmansdale a small up-faulted block of Martinsburg shale bounded by northwest-southeast-trending faults interrupts the belt of carbonate rocks. Although the block appears to be structurally anomalous it is probably related to Yellow Breeches thrusting (D_3) rather than faulting of the Triassic Basin, because these faults are apparently overlapped by Triassic strata.

The Allendale fault is an extensive normal fault dipping 60° southeast where it is exposed along Yellow Breeches Creek at Allendale. Displacement here is estimated to be about 650 feet (200 m). The fault developed late in the sequence of deformations (D_4), as between Rossmoyne and Winding Heights it apparently links with faults that displace Triassic strata. This fault probably extends at least 5 miles (8 km) into Dauphin County near Swatara Crest and may extend beyond this for a considerable distance northeast (MacLachlan, 1967, Plate I).

Folds

Strata on the Yellow Breeches thrust sheet are part of the inverted lower limb of a regional nappe. Based on cleavage, the lower limb trends about N70E through the area, and although the cleavage here is S_1 partially reoriented by D_3 movement, the trend approximates the regional nappe trend.

Some mesoscopic, antiformal*, and synformal* folds reflect the D_1 nappe event and are recognized by gentle plunges either northeast or southwest, with axial surfaces inclined northwest or southeast but dipping more steeply than cleavage in the latter. Interlimb angles of these folds are 70° to 80°. Many of these folds have been partially reoriented during D_3, because the hinges are now normal or subnormal to A_3 lineations which indicate direction of tectonic transport.

Some mesoscopic folds approach the geometry of reclined* folds in that the fold hinges plunge down the cleavage, parallel to A_3; the axial surface is parallel to cleavage; and the folds are virtually isoclinal. These folds are considered $B \perp B'$ folds, of the reclined type developed during D_3, and are probably reoriented F_1 folds developed under conditions described by Flinn (1962). There appears to be a spectrum of reclined folds ranging from those reoriented normal to A_3 to those oriented parallel to A_3 ($B \perp B'$). As A_1 and A_3 differ only by about 17° (MacLachlan and Root, 1966) it is difficult to determine the extent of rotation in folds essentially parallel to A_3 lineation. Reorientation in F_3 decreases progressively away from the Yellow Breeches thrust, so that F_3 folds are local in distribution whereas F_1 folds are widely distributed except where they are close to the thrust.

Another class of folds having B ⊥ B′ geometry is recognized. These folds are considered to be B ⊥ B′ upright folds in which axial surfaces are vertical, interlimb angles are large (>100°), and the hinges plunge down the dip of regional cleavage parallel to A_3. These folds undoubtedly formed during D_3 and are the only primary F_3 folds on the thrust sheet. Farther from the thrust these folds decrease in occurrence. The B ⊥ B′ upright and reclined folds are genetically and temporally related to geometrically similar folds developed in the Cumberland Valley sequence beneath the Yellow Breeches thrust, and as such their presence diminishes above and below the thrust as the D_3 stress effects at the thrust diminish.

At the Hempt Bros. quarry, within a zone of movement at the base of the Yellow Breeches thrust sheet, a series of small open kink folds (Figure 19) are developed in platy limestone. The kink folds are post main D_3, however. They may relate to late-stage residual stress of the D_3 system. The closely spaced anisotropy*, due to the platy character of the rocks, within the movement zone may account for development of a kink fold rather than some other type of fold.

Cleavage

One pervasive tectonite cleavage with bedding largely transposed into parallelism is recognized in the carbonate rocks. In the Martinsburg shales several minor cleavages are recognized in addition to the principal cleavage which is that of the carbonate rocks. These minor cleavages, which grade into crenulations and kink bands, have not been studied systematically. Within the mapped area the principal cleavage dips southeast at 20° to 30°, although locally it is folded.

Evidence on the age of this cleavage is obtained principally from Dauphin County. The cleavage is shown to be refolded about an inclined axis and to be locally cut by S_3 cleavage near the Yellow Breeches thrust (MacLachlan, personal commun.). Therefore, the cleavage is considered to be S_1 cleavage.

This cleavage has been partially reoriented during D_3 movement of the Yellow Breeches thrust sheet. Evidence for this is discerned from B ⊥ B′ upright and reclined folds developed in cleavage and from extensive development of A_3 lineations on the cleavage. In essence, during D_3 the S_1 surface was utilized as the movement surface adjacent to the Yellow Breeches thrust.

Lineation

A pervasive southeast-plunging lineation is present on the cleavage and is especially well developed on the limestones, where it is expressed as "streaking" (Tobisch and Glover, 1971). Streaking refers to the collective minor features that indicate movement of the rock mass, and includes mineral elongation and development of aligned minerals, fine grooving on cleavage or transposed bedding, and slickensides associated with calcite recrystallization on cleavage or transposed bedding surfaces. That this is indeed a movement direction is shown in the Epler Formation by crinoid columnals extended parallel to this lineation. Figure 20 shows the streaking lineations measured on the Yellow Breeches plate. These demonstrate a uniform persistence, and their geometry can be detected in the reclined folds in the Martinsburg several miles to the north (Appendix 3-B).

The lineations on the Yellow Breeches thrust sheet in this area bear the same orientation as those in the Cumberland Valley sequence immediately below the thrust sheet; also, $B \perp B'$ upright and reclined folds are developed parallel to this lineation in the rocks above and immediately below the thrust. Therefore, this lineation is considered to be an A_3 lineation formed during D_3 movement of the Yellow Breeches thrust sheet.

In Dauphin County MacLachlan and Root (1966) and MacLachlan (personal commun.) observed an earlier lineation, presumably A_1, at about 17° to A_3 lineation. Only at one locality in the mapped area are

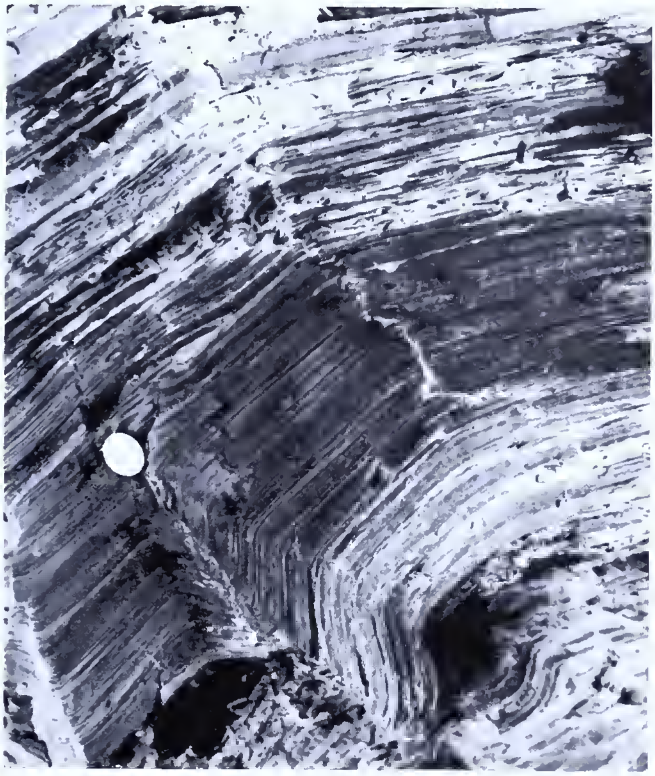
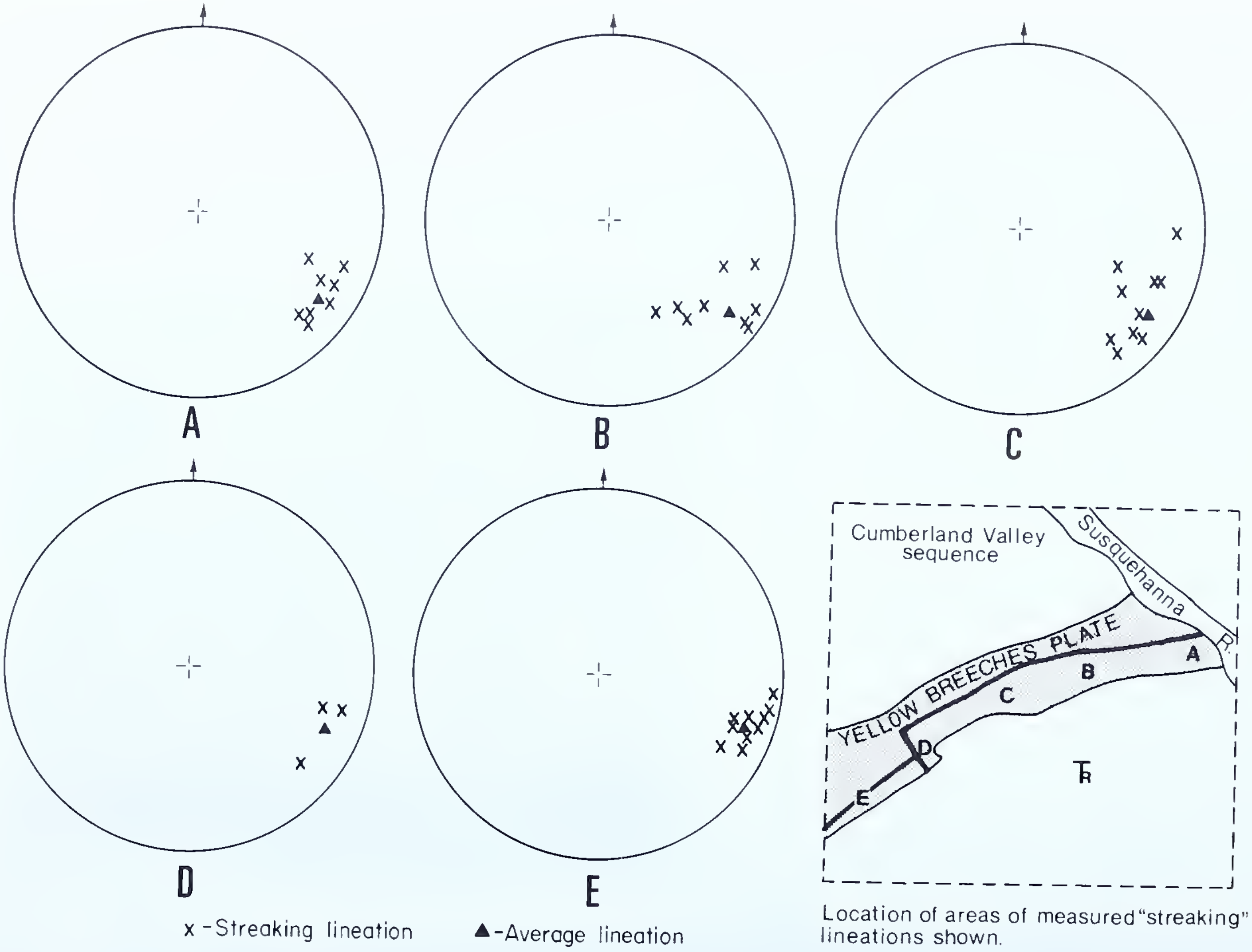


Figure 19. Kink folds in movement zone at base of the Yellow Breeches thrust sheet, Hempt Bros. quarry, Lower Allen Township.



x -Streaking lineation ▲-Average lineation

Location of areas of measured "streaking" lineations shown.

Figure 20. Streaking lineations developed on carbonate rocks of the Yellow Breeches thrust sheet. Inset map shows location of the stereonets.

these two sets of lineations less than 20° apart, which indicates that they possibly may represent A_1 and A_3 lineations. It is expected that farther from the thrust the development of A_3 will decrease and A_1 will dominate.

Joints

Rocks on the Yellow Breeches thrust sheet are traversed by a complex, extensive joint system. Joint sets undoubtedly formed at different times in response to different stress systems that prevailed during the various deformations, but it was not possible to relate them to any particular deformational event.

Joints in the carbonate rocks are spaced at intervals of a few feet. There are generally two prominent sets visible, one of which is about normal to A_3 lineation (Figures 11, 20, and 21). The joints are frequently filled with white crystalline calcite, but often the calcite is dissolved and secondary enlargement by ground-water solution has produced joint-controlled fissures.

The shales are more jointed than the carbonate rocks. Spacing of joints ranges from a few inches to a foot, and frequently three prominent sets occur. The joints are usually unfilled by secondary mineralization, and separation across the joints is 0.5 to 1 mm. No statistically significant pattern of joint distribution is apparent on a joint-pole fabric diagram (Figure 21).

STRUCTURE IN THE TRIASSIC BASIN

The deformation that caused the northwestward monoclinal rotation of Triassic strata is the latest and least intense of the four deformations recognized in the area. This deformation involved external body rotation, normal faulting, and possibly local gentle folding.

Faults

The Allendale fault, although restricted to Paleozoic rocks, is considered to be related to the Triassic Basin. It parallels the structural grain along much of its extent on the Yellow Breeches thrust plate and is clearly defined where carbonate rocks are faulted against shales, but obscure where shale is faulted against shale. The Lisburn fault is subnormal to the structural grain and clearly offsets the Triassic-Paleozoic contact near Lantz Cemetery. It undoubtedly links with the Allendale fault on the north. The Lisburn fault is further extended through Triassic rocks southeastward along a structural orientation domain boundary, but there are not sufficient data here to determine if the boundary is actually a fold or a fault. The Allendale and Lisburn faults, as interpreted, form the corner of a block downdropped on the southeast. Along Yellow

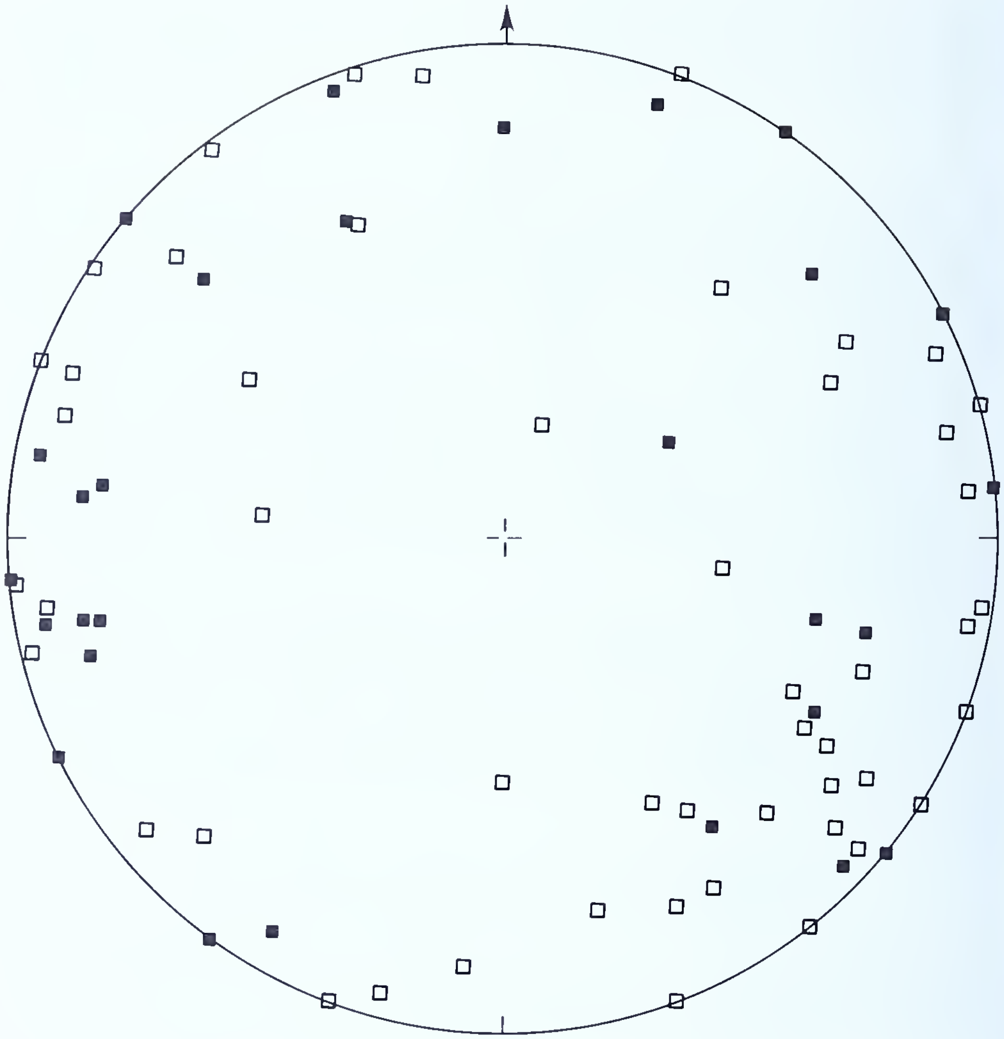


Figure 21. Joint pole diagram of the Martinsburg Formation (solid squares) and carbonate rocks (open squares) on the Yellow Breeches thrust sheet.

Breeches Creek in Allendale the Allendale fault is clearly exposed as a normal fault dipping 60SE. Displacement is estimated to be about 690 feet (210 m). Normal fault movement is inferred for the Lisburn fault based on stratigraphic displacements and drag relations at the fault.

A few small faults offset the Triassic-Paleozoic basement contact at the north margin, but it is difficult to trace them within the Triassic Basin. Stose and Jonas (1939) mapped two small faults offsetting the York Haven pluton near Newberrytown, but little evidence was found to support this, and those faults are omitted on this map. There are a couple of outcrops that show minor down-on-the-southeast normal faulting with displacement usually less than 1 foot (0.3 m).

Folds

No folds are mapped in the Triassic Basin portion of this report area. However, the southern extension of the Lisburn fault may be a fold hinge rather than a fault. Certainly at the north margin the Lisburn fault demonstrates displacement. However, as the fault is projected south, beyond Lisburn, the displacement may transfer to a fold.

Two bedding domains* separated by the Lisburn fault are distinguished on the geologic map (Plate 1). Average bedding in the eastern domain dips 335/40° (Figure 22a) and in the western domain dips 267/25° (Figure 22b)—a strike difference of 70° and dip difference of 15°. The eastern domain has considerable dip scatter, reflecting local strike-parallel belts with steep (up to 70°) dips. The domains are a consequence of block faulting of the basement along the Allendale-Lisburn faults, but south of Lisburn the fault may pass into a fold, and the two domains may be the north and south limbs of an anticline plunging 280/25°.

Joints

Visual inspection of the geologic map (Plate 1) indicates that east of the Lisburn fault joints are generally systematically related to bedding. One set, usually subvertical, is oriented normal to bedding strike. The other set parallels bedding strike and dips approximately normal to the bedding. West of the Lisburn fault there is much deviation from this orthogonal joint system. The lack of preferred orientation on the joint-pole diagram (Figure 23) is due to variation in the local bedding. A broad maximum on northeast-southwest-trending joints dipping moderately to steeply southeast and a broad secondary maximum of northwest-southeast-trending subvertical joints is apparent from this fabric diagram.

Joints in the domain southwest of the Lisburn fault (Figure 23b) define a broad maximum of northeast-southwest-trending joints dipping steeply to subvertically northwest and southeast. These maxima do not define a bed-normal strike-parallel joint system, but rather they conform to the orientation of the joint system in the domain east of the Lisburn fault. The cause of this is not evident, but possibly may be due to post-faulting joint development.

Spacing of joints in the shales and siltstones ranges from 2 inches to 1 foot (5 to 30 cm). The joint surfaces are somewhat curved and not extensive. In sandstones and pebbly sandstones joints are spaced from 6 inches to 6 feet (15 to 180 cm), but spacings of 1 to 2 feet (30 to 60 cm) are most common. Here joint surfaces are planar and extensive with occasional secondary mineralization of quartz or calcite. Joints are

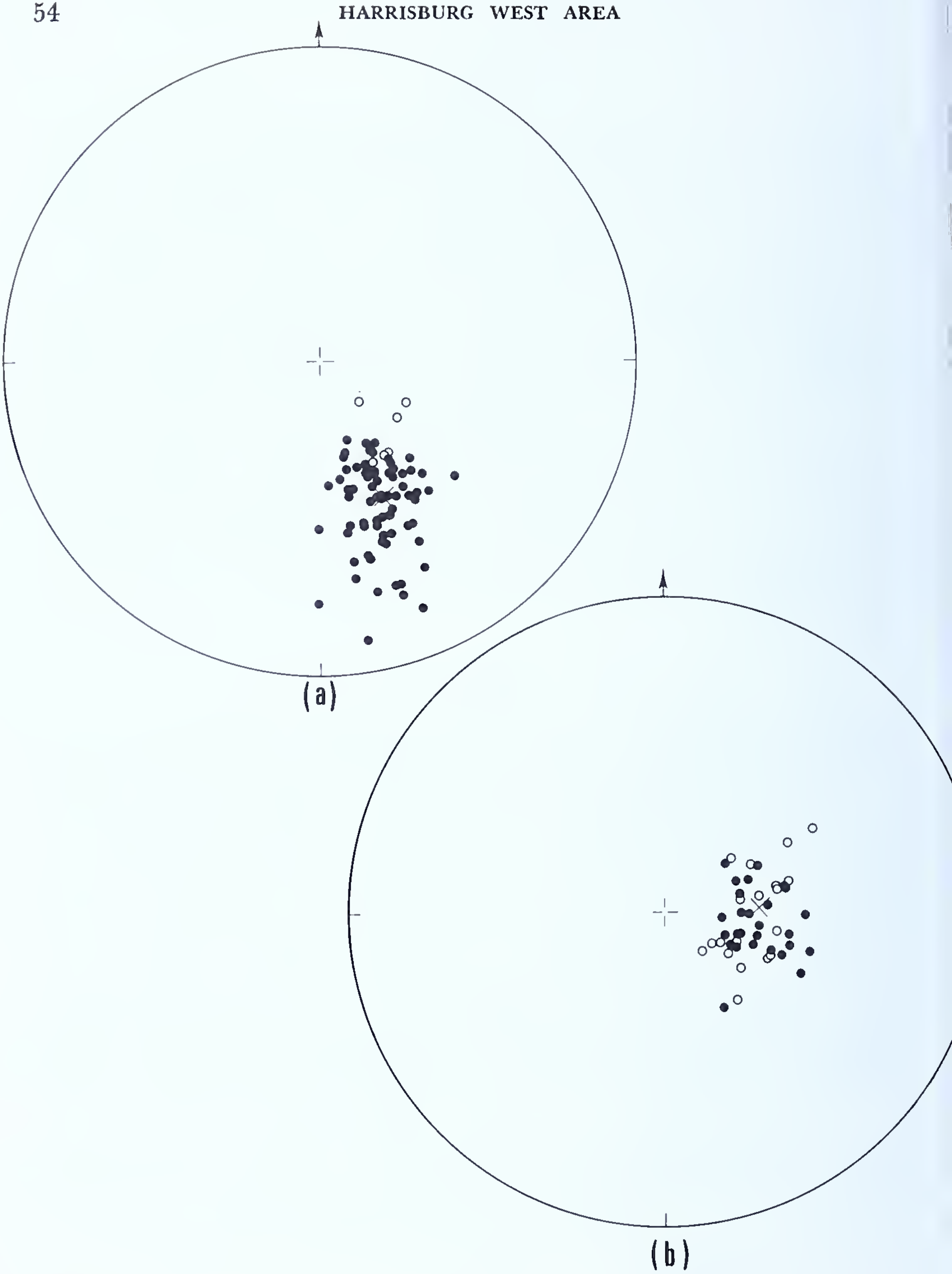


Figure 22. (a) Bedding pole diagram in Gettysburg Formation northeast of Lisburn fault. Solid circles are at a distance from domain boundary and open circles are near domain boundary. Average monocline bedding = x.

(b) Bedding pole diagram in Gettysburg Formation southwest of Lisburn fault. Solid circles are at a distance from domain boundary and open circles are near domain boundary. Average monocline bedding = x.

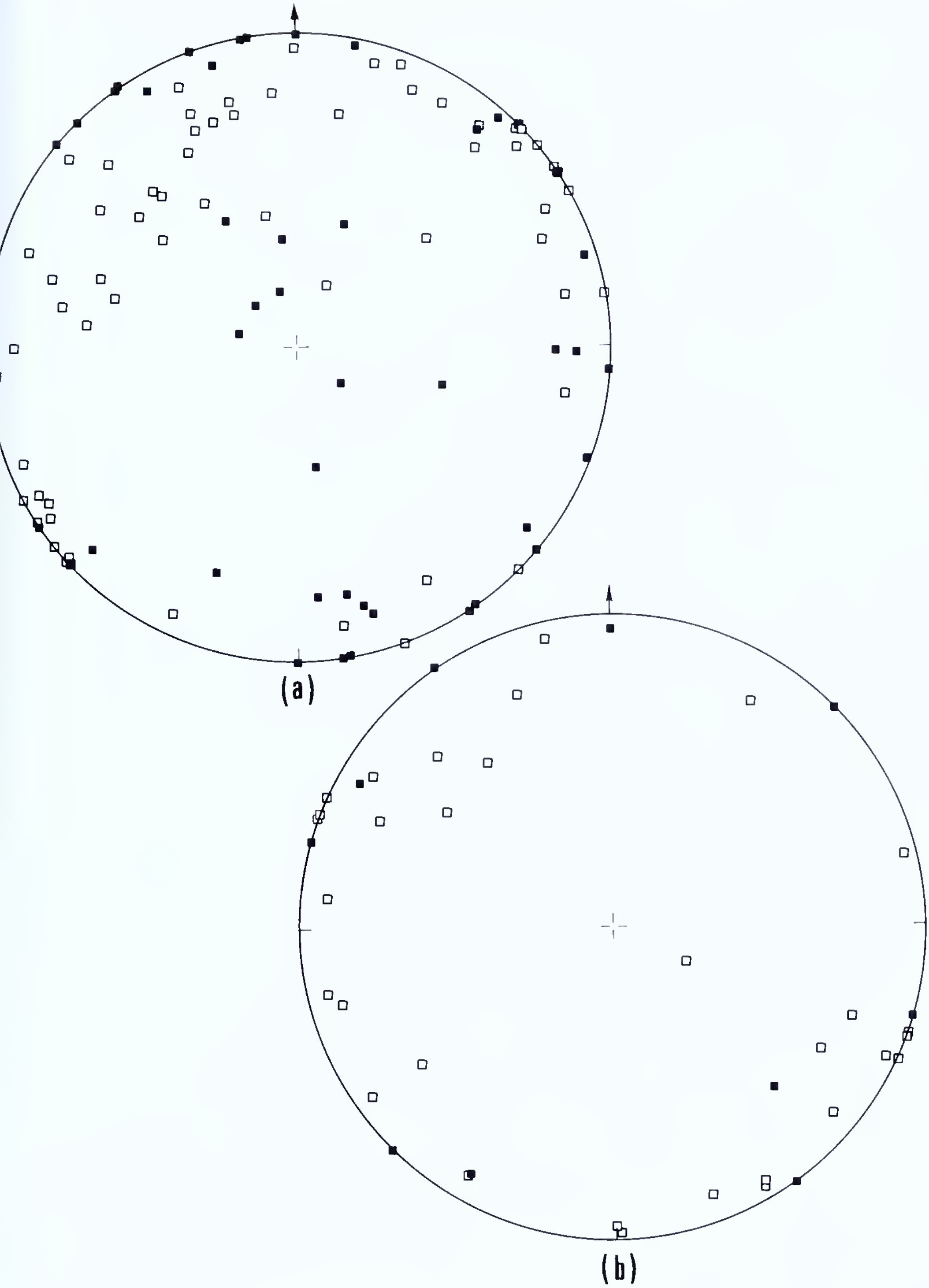


Figure 23. (a) Joint pole diagram of area northeast of Lisburn fault. Open squares from Gettysburg Formation, solid squares from diabase pluton near Reesers Summit.

(b) Joint pole diagram of area southwest of Lisburn fault. Open squares from Gettysburg Formation, solid squares from diabase pluton at Pinchot Park.

sparse in the fanglomerates, spaced at intervals of several or more feet, frequently have irregular surfaces, and generally are not extensive.

Joints in the diabase plutons are more complex than in the enclosing sedimentary rocks. At the northern margins, where plutons are discordant, as in the areas about Reesers Summit (Figure 23a), there are several broad maxima of joint orientations including low to vertical dips. Many surfaces are curviplanar to irregular and fan markedly. Spacing of the joints is irregular, with some 6-foot- (1.8-m-) wide sheeting zones in which joints are spaced at 2 to 4 inches (5 to 10 cm). Joint spacing in general is highly variable and ranges from 0.5 to 3 feet (0.15 to 0.9 m). The surfaces are frequently mineralized and slickensided. Some of the joints are probably cooling joints, which accounts for the extreme variation in joint orientation.

At their southern margin, where plutons are generally concordant with the enclosing strata, joints form more regular, planar surfaces, evenly spaced, generally at from 3 to 8 feet (0.9 to 2.4 m)—as at Pinchot Park (Figure 23b). The joints are subvertical and reflect the joint system of the enclosing sedimentary rocks. Blocks and boulders derived from these portions of the pluton are usually much larger than those from the northern portions of the pluton and are more suited to working for ornamental purposes, although they are more difficult to blast and remove.

Local Overlap at the North Margin

The northwest margin of the Gettysburg Basin is sharply defined where the proposed post-depositional border fault at the north margin separates Precambrian metavolcanics and Cambrian quartzites from Triassic strata. However, from Dillsburg at least to Highspire the northwest basin margin is not as well defined. Here basement rocks north of the basin margin are Cambro-Ordovician limestones similar to those that floor the basin at York Springs. Unambiguous evidence demonstrates that a narrow, thin strip of Triassic rocks at the north margin overlaps the basement. It is concluded that a border fault must be present a few hundred feet, or less, southeast of the contact and links with the regional border fault extending from Dillsburg southwest to Frederick, Maryland.

Localities along the north margin at Highspire (Faill, 1973) and along the Turnpike (McLaughlin, 1961) expose Triassic strata overlapping Paleozoic carbonate basement floor. The Triassic strata, and the basement floor which parallels them, are inclined at less than 10° south. At the north margin, in the Lemoyne quadrangle, a number of domestic water wells, a water well at Messiah College, and extensive Turnpike foundation drilling all passed through Triassic strata and into Paleozoic limestone showing the basement floor sloping gently southeast. In a few places closely spaced core drilling shows karst development on the Paleozoic limestone below the Triassic strata. It is presumed that the overlying Triassic strata also dip gently southeast here.

A few hundred feet, or less, south of the north margin of the Triassic Basin Triassic strata dip moderately northwest and maintain this dip for miles to the south margin. A major postdepositional southeast-dipping normal fault is inferred between the thin strip of gently southeast dipping Triassic strata and the moderately northwest dipping strata of the main portion of the basin. This fault may be substantiated by relations in a water well at the New Cumberland Army Depot located just 1,800 feet (550 m) south of the north margin. It was drilled to a depth of 700 feet (215 m) and did not pass out of Triassic strata, indicating that the basement may be at considerable depth and that the fault is located between the well and overlapping beds at the north margin. In the mapped area the position of the fault forming the north margin of the Gettysburg Basin cannot be determined precisely. The fault position on the cross sections (Figure 24 and Plate 1) is located so as to exaggerate the thin strip of overlapping Triassic strata north of the fault.

Structure at the North Margin

The major structural problem of the Triassic Basin is concerned with whether the north margin of the basin is faulted or unfaulted, and, if the former, the extent and age of the faults. Two different structural models have been proposed to explain the observed structures in the Gettysburg Basin.

In a series of papers Stose (1932, 1949, and 1953) and Stose and Jonas (1939) developed structural concepts principally to account for the presence of Paleozoic basement exposed through Triassic sedimentary beds at York Springs and elsewhere. In essence, recognizing that the faulting at the north margin is relatively minor, they propose that a major normal fault of Triassic age is buried several miles southeast of the present Triassic north margin. Diabase has intruded along the buried fault. The downdropped area southeast of their major buried normal fault is the deep part of the Triassic Basin containing about 20,000 feet (6,000 m) of northwesterly dipping Triassic strata. The area between the buried fault and present faulted Triassic north margin is covered by a horizontal thin veneer of younger Triassic strata through which a horizontal Paleozoic basement floor is exposed at several places. The minor normal faults at the north margin of the basin were initiated at the same time as the buried fault, but displacement on them was much less. Subsequently additional normal faulting occurred on the north margin fault. Significant elements of this hypothesis are: 1) major normal faulting and northwestward rotation of strata occurred prior to termination of Triassic sedimentation; 2) the deepest part of the Triassic Basin is not along the north margin as would be expected in a simple half-graben structure, but rather towards the center of the present basin; 3) normal faulting at the present north margin continued to the end of Triassic deposition but did not involve bed rotation; and 4) these features are accounted for by an extensional model.

Faill (1973), in a regional structural synthesis of the Newark-Gettysburg Basin, concluded that these basins were not half grabens because, according to his interpretation, there is no continuous system of normal faults at the basin north margin. Instead, he proposed Triassic sediment filling of a simple downwarp during a crustal extensional phase. Following deposition, the basin was tilted north during compressional development of a crustal syncline with simultaneous development of a related system of folds and faults. Erosion of this syncline has preserved a north-dipping monocline.

Both models are in accord that the deepest part of the Triassic Basin is not at the north margin, but rather lies in what is now the middle part of the basin. They differ significantly as to the temporal development and intensity of normal faulting. Development of an accurate and precise structural model is no mere intellectual exercise but has direct practical utility. For example, if at the north margin of the Triassic Basin carbonate rocks are at a shallow depth for a considerable distance, then an important new aquifer is defined. It would be possible in many areas to drill through Triassic strata and tap the more prolific yielding carbonate rocks as an important source of ground water. In the realm of mineral exploitation it is possible that the valuable high-calcium Annville limestone of Dauphin County (MacLachlan, 1967) may be present at a shallow depth below Triassic sedimentary rocks. There also may be mineralization at the contact of the Paleozoic limestone and diabase pluton, which would be at minable depth.

Evidence has not been found in the mapped area to resolve the problem of the structure of the Gettysburg Basin. However, some local relationships are apparent; when integrated with observed features elsewhere in the basin, the following structural model may be postulated.

The Gettysburg Basin is a complex, tilted, step-faulted block composed of a series of postdepositional, bedding-strike-parallel, southeast-dipping antithetic faults across which the originally horizontal strata have been rotated northwest. The faults progressively downdrop Paleozoic basement so that the deepest part of the basin is near the present middle part of the basin. Faulting occurred after the Triassic strata were deposited in a simple crustal downwarp. The north margin of the basin is faulted,

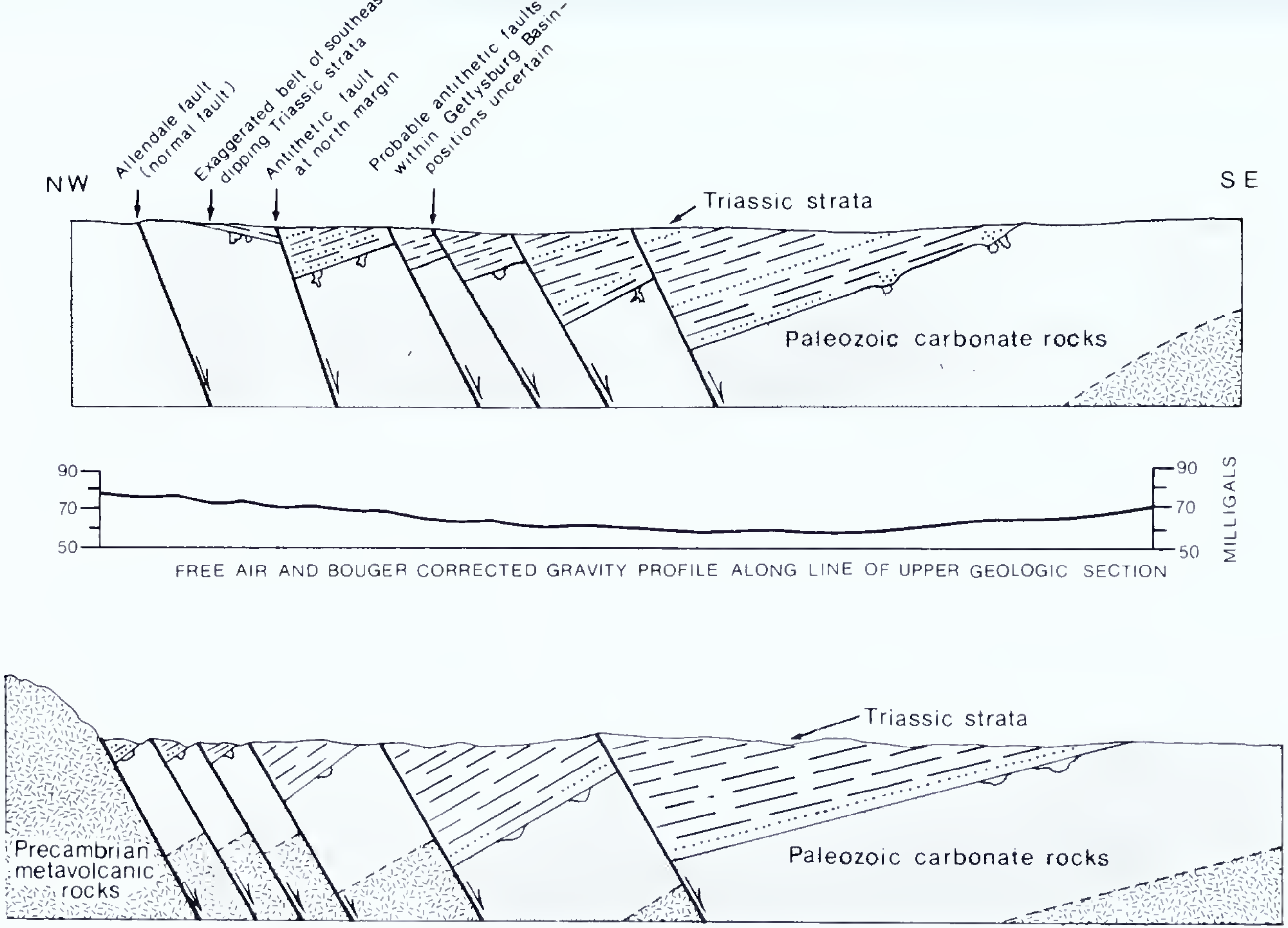

NW
S E
Allendale fault (normal fault)
Exaggerated belt of southeas dipping Triassic strata
Antithetic fault at north margin
Probable antithetic faults within Gettysburg Basin–positions uncertain
Triassic strata
Paleozoic carbonate rocks
90
70
50
MILLIGALS
FREE AIR AND BOUGER CORRECTED GRAVITY PROFILE ALONG LINE OF UPPER GEOLOGIC SECTION
Triassic strata
Paleozoic carbonate rocks
Precambrian metavolcanic rocks

Figure 24. Generalized cross sections through the Gettysburg Basin showing proposed extensive antithetic fault development. Diabase plutons omitted. Upper section through Harrisburg West area; lower section through York Springs area to south.

and a number of large faults are recognized and postulated within the basin. Slightly younger faults, at large angles to the basin margin, offset the north margin and serve as boundaries across which different bedding domains are generated. In the Harrisburg area, a strip of Triassic strata, as much as several hundred feet wide at the north limit of the Triassic Basin, dips gently southeast on a basement surface that slopes gently southeast. These beds are considered as north of the most northerly antithetic fault, and probably are only slightly rotated from their original depositional attitude. Clearly this model is simplistic with respect to both structure and stratigraphy. It does not recognize the effect of possible local fault-block movement during deposition of Triassic strata.

In some places near the north margin, but within the Gettysburg Basin, Triassic strata rest unconformably on Paleozoic basement exposed at the surface (Stose, 1953). A fault is inferred between these rocks and the main mass of Triassic rocks to the southeast. It has not been established if the basal Triassic beds here are coeval with lower New Oxford strata at the south margin or are considerably younger. In either case these relations demonstrate that there is not an uninterrupted sequence of Triassic rocks that is progressively younger from the south to north basin margin; rather they confirm the structural and stratigraphic complexities postulated within the basin.

Figure 24 presents two generalized cross sections through the Gettysburg Basin according to these proposed ideas. The sections are necessarily generalized, as locations of a number of postulated antithetic faults are only inferred.

MINERAL RESOURCES

INTRODUCTION

Stone, sand and gravel, and clay products are the principal mineral resources produced in the mapped and immediately adjacent areas. These products are evaluated in this section in terms of geology, composition, and utility. The mapped area is heavily urbanized and mineral extraction is considerably restricted by zoning ordinances, so that, although there are occurrences of significant economic resources, these are not readily exploitable. It is hoped that planners will take cognizance of the more significant and scarce mineral resources and plan for their exploitation in future development of the region. Particularly because of urban redevelopment as well as suburban expansion, there is a great need to locate nearby occurrences of construction aggregates such as sand, gravel, and crushed stone. The availability of those in close proximity means a vast saving in the cost of new projects.

In addition to carbonate rocks and shales, which constitute the principal mineral resources, Stose and Jonas (1939) recorded magnetite and hematite, copper, garnet, and coal from Triassic rocks in the area. Specific mineral occurrences are discussed by Smith in the section on Triassic diabase.

MAGNESIUM AND MAGNESIUM COMPOUNDS

Relatively pure dolomite rock (calcium magnesium carbonate) is used in places for the production of magnesium metal, and for compounds such as refractory magnesia, basic magnesium carbonate, or magnesium chloride (Table 4). No rigid specifications exist for these purposes, but generally the dolomite should contain more than 40 percent $MgCO_3$ and less than 1 percent each of SiO_2, Fe_2O_3, and Al_2O_3. Impure dolomite rock is frequently an excellent source of aggregate or agricultural dolomite.

In the mapped area only the Pinesburg Station Formation is composed of dolomite. It is calculated to be 208 feet (63 m) thick (Figure 25; Appendix 1), and only three beds of limestone, 1 to 3 feet (0.3 to 0.9 m) thick, are present; the remainder is composed wholly of dolomite. Eight samples from this section contain from 5 to 15 percent acid-insoluble residue, primarily silica, iron, and aluminum oxides. Chert is locally a common constituent of this unit and is deleterious both in quality control of the product and in the milling operation. From these data it would appear that, despite the thick amount of dolomite present, the Pinesburg Station is not suitable for purposes requiring a low silica content.

Three samples from the measured section (Appendix 1) contained 36 to 37 percent $MgCO_3$ and 5.0 to 6.6 percent SiO_2 (Table 5, samples 5-7). The Pinesburg Station Formation was also sampled outside of the mapped area to test its composition. Four samples were chemically analyzed from a section just west of Carlisle (Table 5, samples 1-4), and they contained 33 to 39 percent $MgCO_3$ and 6.6 to 10.3 percent SiO_2. This indicates that the formation in this area contains excessive SiO_2 and is not suitable for purposes requiring relatively pure dolomite.

However, dolomite of the Pinesburg Station Formation does meet the requirements for agricultural dolomite ($CaCO_3 + MgCO_3 = 85\%+$), as it normally contains more than 85 percent carbonate (Figure 25; Table 5). The dolomites appear sufficiently massive and dense to serve as a source of aggregate.

The Lower Cambrian Tomstown Formation, which is not present in the mapped area but occurs in adjacent quadrangles, is the only other unit in the Cumberland Valley that contains thick sequences of dolomite. Dolomite beds sampled near Williams Grove contain 38 percent $MgCO_3$ and 7.8 percent SiO_2 (Table 5, sample 5). Therefore this unit also contains excessive SiO_2 and is not suitable for uses requiring relatively pure dolomite. It is, however, suitable for agricultural dolomite and appears to be sufficiently massive and dense to serve as a source of aggregate.

Table 4. *Chemical Requirements for Uses of Limestone and Dolomite*

Uses	Chemical requirements					
	$MgCO_3$	$CaCO_3$	SiO_2	Fe_2O_3	Al_2O_3	Other
Agricultural dolomite	$\geq 85\%$					
Dolomite for refractories	$\geq 37.5\%$		$\leq 1\%$	$\leq 1\%$	$\leq 1\%$	
Magnesium carbonate for lime (magnesium)	21-31.5%					
Limestone and magnesium limestone for steel flux (blast furnaces)	8-31%		$<5\%$		$<2\%$	Phosphorus $<0.01\%$
Limestone and dolomite for glass	$>98\%$	$>98\%$		$\leq 0.05\%$		
Limestone for paint and filler	$<1\%$	$>96\%$	$<2\%$	$<0.25\%$		SO_3 $<0.1\%$
Limestone for lime (high calcium)		$>97\%$, $>98\%$ preferable				
Limestone for steel flux (open hearth)		$>97\%$, $>98\%$ preferable				
Limestone for general chemical use		$>97\%$, $>98\%$ preferable				
Agricultural limestone		$\geq 85\%$				
Limestone for Portland cement	$<6.3\%$	Variable				

CHEMICAL GRADE LIMESTONE

High-calcium limestones can be used in diverse ways. Portland cement, lime, steel fluxstone for open hearth and blast furnaces, general chemical use, glass manufacture, and paint filler are but some of the common uses. Chemical requirements of the limestone utilized in these industries are summarized in Table 5. For such high-calcium-limestone uses the $CaCO_3$ should be in excess of 95 percent and the SiO_2 correspondingly low.

The St. Paul Group limestones have historically been the source of high-calcium rocks in the Cumberland Valley. Other limestone formations contain excessive SiO_2, Al_2O_3, and Fe_2O_3 and do not attain the requirements of high-calcium limestone (Table 4). Locally some beds of other formations have high-calcium-limestone composition, but these are uneconomical as they require selective quarrying. Some high-calcium limestones contain chert in varying amounts, which is deleterious to maintenance of quality control and damages milling equipment.

In the mapped area there is only one demonstrable potential occurrence of high-calcium limestone (Figure 25). Units 49 to 56, which are basal St. Paul Group (measured section, Appendix 1), aggregate to 70 feet (21 m) and average only 2.7 percent acid-insoluble residue (Figure 25) based on eight samples. However, units 50 and 52 are dolomite and consequently present a problem in maintaining $CaCO_3$ quality. The medial part of the St. Paul frequently contains abundant cherts and dolomite beds and is considered unlikely as a source of high-calcium limestone. The upper part of the St. Paul Group is poorly exposed at this section (Figure 25), but samples from units 72, 74, and 76 average 1.7 percent acid-insoluble residue, so that this interval must be considered as a prospective source of high-calcium limestone. Four chemical analyses from this section (Table 6, samples 1-4) confirm that beds in the lower part of the St. Paul approach high-calcium grade. These beds (units 49, 54, and 55) contain more than 93 percent $CaCO_3$ and less than 1.3 percent SiO_2. Sample 5, from the basal 10 feet (3 m) of unit 57, does not attain requisite purity (87 percent $CaCO_3$ and 3.7 percent SiO_2).

A number of partial chemical analyses of random samples from the St. Paul Group at the Hempt Bros. quarry in Lower Allen Township are presented in Table 7 (courtesy of the operators). The analyses indicate that although the amount of acid-insoluble residue may be low, as in samples 1, 2, and 5, these samples contain appreciable amounts of MgO, ranging from 1.25 to 4.17 percent. These analyses are considered to be typical of the medial St. Paul in this area. Because of the relatively large amounts of MgO and its occasionally unpredictable occurrence, it would be difficult to exploit the St. Paul Group here for high-calcium limestone.

Almost 100 years ago Lesley (1879, p. 311-361) made an exhaustive study, including 231 chemical analyses, of what is now termed the St.

Table 5. *Chemical Analyses of Dolomites, Eastern Cumberland County*

TEST	1	2	3	4	5	6	7	8
SiO_2	6.71	6.65	7.29	10.3	6.6	5.2	5.0	7.86
Al_2O_3	.65	.70	.53	1.17	1.1	0.7	0.9	1.58
Fe_2O_3	.27	.48	.26	.84	0.97	0.90	0.98	.89
P_2O_5	.13	.05	.07	.10	0.1	0.1	0.1	.16
MgO	18.7	18.3	17.6	15.8	17.3	18.0	17.8	18.2
($MgCO_3$) **	(39.08)	(38.31)	(36.78)	(33.02)	(36.18)	(37.65)	(37.23)	(38.03)
CaO	29.7	30.5	31.1	30.7	31.8	31.4	31.0	27.1
($CaCO_3$) ***	(53.02)	(54.29)	(55.35)	(54.64)	(56.76)	(56.05)	(55.34)	(48.24)
Total S, as SO_3	.01*	.05	.01	.14	0.16	0.08	0.14	.01*
Sulfate S, as SO_3	.01*	.04	.01	.02	0.3	0.07	0.08	.01*
Na_2O	.01*	.01	.03	.03	0.02	0.03	0.03	.06
K_2O	.36	.34	.21	.67	0.58	0.36	0.43	1.07
Insoluble residue	7.44	7.09	8.79	11.94	9.4	6.6	6.7	10.77
Loss in ignition	43.73	43.42	43.30	41.05	41.0	43.1	43.0	41.99

*Less than

**MgO calculated to $MgCO_3$ by gravimetric factor 2.0915

***CaO calculated to $CaCO_3$ by gravimetric factor 1.785

LOCATION OF SAMPLES

Sample 1. Collected from beds below Prouty's (1960, p. 84-87) section west of Carlisle in fields south of Turnpike; sampled interval from Pinesburg Station Formation, 0-20 ft above base of Pinesburg Station Formation.

Sample 2. As previous, 20-40 ft above base.

Sample 3. As previous, 100-120 ft above base.

Sample 4. As previous, uppermost 10 ft of Pinesburg Station.

Sample 5. Pinesburg Station Formation, 0-10 ft above base of section at Mechanicsburg Naval Supply Depot (40°14′30″N/76°59′58″W).

Sample 6. As previous, 10-30 ft above base.

Sample 7. As previous, uppermost 7 ft of section but excluding a 1-ft limestone bed.

Sample 8. Dolomite from quarry in Tomstown Formation, just south of Williams Grove (40°08′40″N/77°01′54″W); represents 60 ft of section.

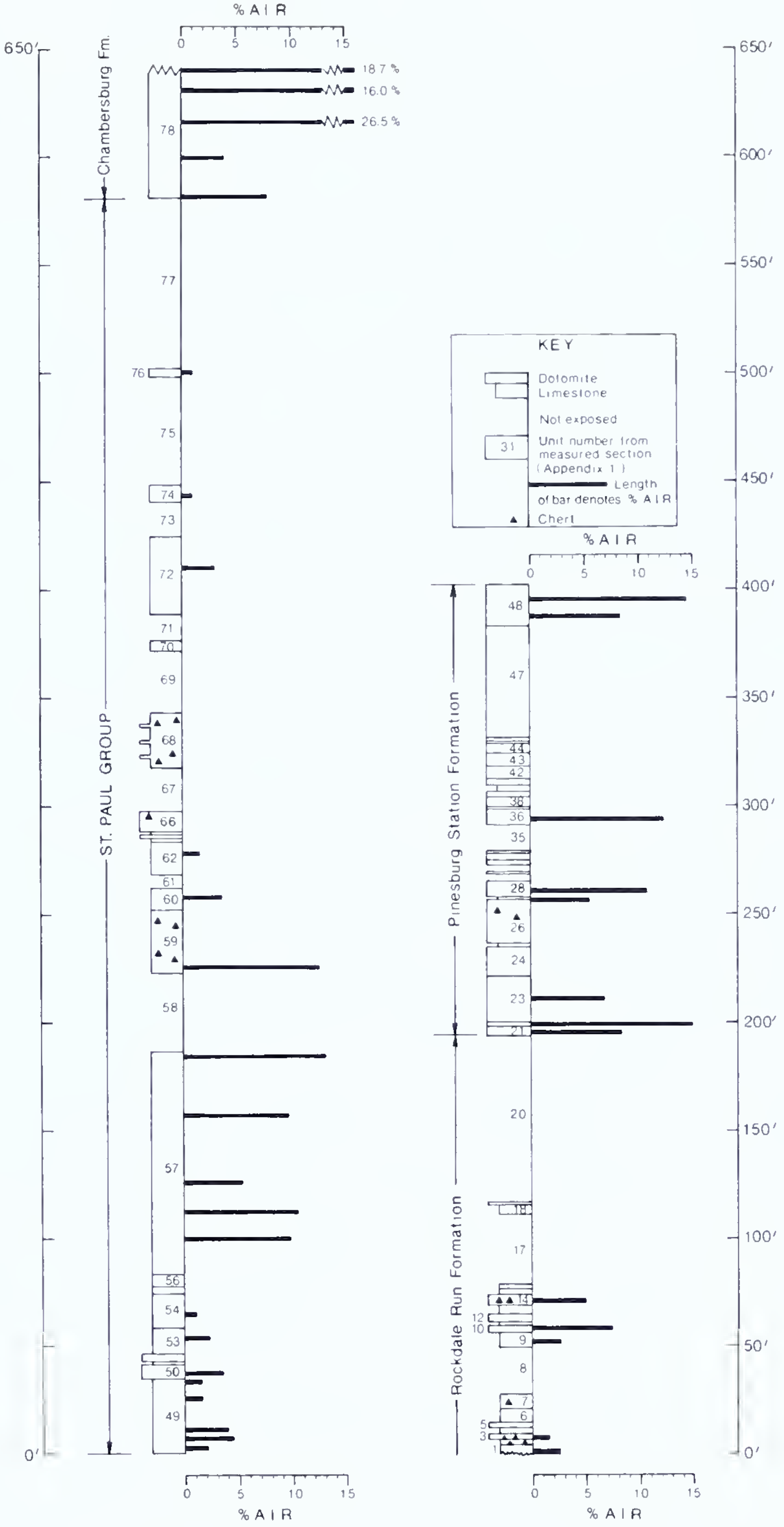


Figure 25. Diagram showing amount and distribution of acid-insoluble residues (A.I.R.) from samples collected at the section measured near Mechanicsburg Naval Supply Depot (see Appendix 1).

Table 6. *Chemical Analyses of the Saint Paul Group, Eastern Cumberland County*

TEST	1	2	3	4	5	6	7	8	9	10
SiO_2	.87	1.30	1.00	.76	3.75	2.02	1.03	1.67	1.27	2.05
Al_2O_3	.54	.37	.30	.22	.75	.28	.08	.22	.13	.33
Fe_2O_3	.18	.16	.16	.13	.31	1.53	.63	.79	.40	.57
P_2O_5	.02	.02	.16	.02	.09	.20	.03	.20	.11	.02
MgO	1.43	1.64	1.59	.73	3.70	1.65	.48	6.28	5.60	6.08
($MgCO_3$) **	(2.99)	(3.43)	(3.32)	(1.53)	(7.73)	(3.45)	(1.00)	(13.13)	(11.70)	(12.71)
CaO	53.8	52.6	52.8	54.4	49.1	50.6	53.0	46.6	48.8	47.5
($CaCO_3$) ***	(95.76)	(93.63)	(93.98)	(96.83)	(87.40)	(90.32)	(94.60)	(83.18)	(87.10)	(84.78)
Total S, as SO_3	.01	.01*	.02	.01*	.06	.02	.04	nil	.04	.19
Sulfate S, as SO_3	.01*	.01*	.01*	.01*	.01*	.01	nil	nil	nil	nil
Na_2O	.02	.02	.01*	.01*	.01	.01	.05	.07	.03	.03
K_2O	.11	.22	.09	.14	.26	.53	.18	.38	.16	.16
Insoluble residue	1.52	1.96	1.39	1.12	4.82	1.56	0.26	1.58	1.31	3.31
Loss in ignition	43.16	43.56	43.66	43.69	42.46	43.28	44.69	43.95	43.98	43.16

TEST	11	12	13	14	15	16	17	18	19	20
SiO_2	6.89	1.94	4.60	4.43	2.46	5.40	6.50	4.12	3.97	1.54
Al_2O_3	.48	.28	.23	.19	.30	.99	1.45	.76	.80	.37
Fe_2O_3	1.33	.51	.68	1.30	1.02	.48	.50	.33	.33	.17
P_2O_5	.10	.03	.03	.07	.28	.05	.08	.08	.09	.05
MgO	3.55	9.45	7.05	8.73	10.00	8.94	7.85	4.52	5.30	2.81
($MgCO_3$) **	(7.42)	(19.75)	(14.73)	(18.25)	(20.90)	(18.68)	(16.41)	(9.44)	(11.08)	(5.87)
CaO	45.6	44.1	46.1	42.5	42.4	41.1	40.7	47.3	47.1	51.1
($CaCO_3$) ***	(81.35)	(78.11)	(82.28)	(75.86)	(75.68)	(73.15)	(72.44)	(84.19)	(83.84)	(90.95)
Total S, as SO_3	.47	.07	.12	.06	.10	.05	.18	.06	.01*	.01
Sulfate S, as SO_3	nil	.01	.02	.01	.01	.01*	.02	.01*	.01*	.01*
Na_2O	.04	.03	.03	.04	.04	.04	.05	.04	.04	.03
K_2O	.45	.12	.12	.15	.07	.38	.47	.21	.22	.10
Insoluble residue	6.40	1.98	6.24	4.71	3.56	7.78	9.73	5.58	5.19	2.15
Loss in ignition	41.12	43.72	41.75	42.53	43.45	41.79	41.30	42.24	42.35	43.51

*Less than
**MgO calculated to $MgCO_3$ by gravimetric factor 2.0915
***CaO calculated to $CaCO_3$ by gravimetric factor 1.785

LOCATION OF SAMPLES

Sample 1. Section at Mechanicsburg Naval Supply Depot (see Appendix 1 for description), 0-10 ft above base of St. Paul Group, from unit 49.
Sample 2. As previous, 10-20 ft above base section, from unit 49.
Sample 3. As previous, 20-30 ft above base section, from unit 49.
Sample 4. As previous, from units 54 and 55.
Sample 5. As previous, from basal 10 ft, unit 57.
Sample 6. From section at Huston's Mill, collected from Dyson's (1967, p. 53) unit 6.
Sample 7. As previous, units 9 and 10.
Sample 8. As previous, unit 11.
Sample 9. As previous, unit 12.
Sample 10. As previous, unit 12.
Sample 11. As previous, unit 13.
Sample 12. As previous, unit 17.
Sample 13. As previous, units 18, 19, and 20.
Sample 14. As previous, units 22, 23, 24, 25, and 26.
Sample 15. As previous, units 27, 28, and 29.
Sample 16. From section west of Carlisle (Prouty, 1960, p. 84-87), 0-20 ft above base of St. Paul Group.
Sample 17. As previous, 265-305 ft above base, Prouty's top of unit 1 and unit 2.
Sample 18. As previous, 312-328 ft above base, Prouty's unit 3.
Sample 19. As previous, 329-354 ft above base, Prouty's unit 4.
Sample 20. As previous, 355-415 ft above base, Prouty's unit 6.

Table 7. *Chemical Analyses of the Saint Paul Group, Hempt Bros. Quarry, Lower Allen Township, Cumberland County*

Test	1	2	3	4	5	6	7	8	9	10
SiO_2	1.75	1.69	8.46	4.27	1.93	4.35	2.94	3.90	6.61	3.84
Al_2O_3	.42	.63	1.32	1.00	.11	1.21	.47	1.31	1.14	.71
Fe_2O_3	.14	.16	.44	.49	.45	.16	.23	.65	.33	.23
MgO	1.68	4.17	17.40	16.27	1.25	2.11	2.43	9.94	5.16	1.88
($MgCO_3$) *	(3.5)	(8.7)	(36.4)	(34.1)	(2.6)	(4.4)	(5.1)	(20.8)	(10.8)	(3.9)
CaO	51.91	49.62	29.37	33.38	51.95	50.72	50.21	41.30	44.57	51.86
($CaCO_3$) **	(92.6)	(88.5)	(52.3)	(59.5)	(92.6)	(90.4)	(89.5)	(73.6)	(79.4)	(92.4)
Loss in ignition	43.18	43.63	42.39	44.29	43.02	41.30	42.45	42.00	40.83	41.35

Test	11	12	13	14	15	16	17	18	19	20
SiO_2	5.44	6.37	9.13	8.23	7.83	9.29	8.35	4.97	5.53	6.64
Al_2O_3	1.09	1.21	1.50	1.47	2.55	1.59	1.72	.70	1.05	1.15
Fe_2O_3	.33	.36	1.04	.37	.86	.49	.57	.23	.31	.48
MgO	2.89	1.90	13.27	2.03	14.75	7.10	12.73	1.40	1.91	2.30
($MgCO_3$) *	(6.0)	(4.0)	(27.8)	(4.2)	(30.9)	(14.8)	(26.7)	(2.9)	(4.0)	(4.8)
CaO	48.42	48.96	32.76	48.64	32.33	42.71	34.51	50.33	50.40	48.58
($CaCO_3$) **	(86.3)	(87.2)	(58.4)	(86.7)	(57.7)	(76.2)	(61.5)	(89.7)	(89.8)	(86.7)
Loss in ignition	41.10	40.08	39.71	38.69	39.59	38.71	40.36	40.93	40.76	40.37

*MgO calculated to $MgCO_3$ by gravimetric factor 2.095

**CaO calculated to $CaCO_3$ by gravimetric factor 1.785

Paul Group. Strata in quarries at Lemoyne were sampled on a bed-by-bed basis over a 371-foot (113-m) interval in the lower part of the St. Paul section. The landmarks to which he keyed his section are long gone; however, it is apparent that the lower part of this section is now covered by Interstate 83. The strata at this location are described and summarized by MacLachlan (1967, p. 142-152) but cannot be correlated specifically with Lesley's section. MacLachlan (1967) also plotted the analyses on a ternary diagram. From these descriptions it is obvious that there are significantly more dolomite interbeds in the lower part of the St. Paul Group at the Lemoyne section than in the section measured at the Naval Supply Depot (Appendix 1). Beds 1 through 6 (23 feet (7 m) thick), beds 8 through 20 (45 feet (14 m) thick), beds 34 through 46 (30 feet (9 m) thick), beds 72 through 75 (18 feet (5.5 m) thick), beds 88 through 92 (12 feet (3.7 m) thick), and beds 101 through 109 (23 feet (7 m) thick) analyzed by Lesley meet the requirements of high-calcium limestone. However, this area is completely urbanized, so that surface quarrying is impossible.

Additional sections of the St. Paul Group in proximity to the mapped area were also sampled and analyzed to define their utility. Ten samples were collected (Table 6, samples 6-15) from the Huston Mill section of Dyson (1967), just west of the mapped area. This is only a partial section with the lowest, presumably high-calcium-limestone, beds not exposed. Samples 6 and 7 approach high-calcium character with 90.3 and 94.6 percent $CaCO_3$ and less than 2 percent SiO_2. Samples 8 through 15 contain only 75 to 87 percent $CaCO_3$ and correspondingly higher amounts of SiO_2, so that this portion of the St. Paul is not suitable here for high-calcium use.

Five samples were analyzed from Prouty's (1960) St. Paul section along the Turnpike just west of Carlisle (Table 6, samples 16-20). Only sample 20, representing the interval 355 to 415 feet (108 to 126 m) above the base of the St. Paul, approaches high-calcium character (91 percent $CaCO_3$, 1.5 percent SiO_2). The other samples, which were collected from lower beds, contain only 73 to 84 percent $CaCO_3$ and 4 to 6.5 percent SiO_2, indicating unsuitability for high-calcium use.

IMPURE LIMESTONES

Chemical requirements for Portland cement and agricultural limestone (Table 4) are attained by many of the units. By controlled mixing of shale and additives the Zullinger, Shadygrove, Stoufferstown, Stonehenge, Rockdale Run, and Chambersburg Formations are suitable as a limestone source for Portland cement. However, the variability in SiO_2, Al_2O_3, and Fe_2O_3, as reflected by the content of acid-insoluble residues of these formations, necessitates careful quality-control studies of the limestones. These same units are all suitable for agricultural limestone, which requires less quality control as the compositional standards are less rigorous than for Portland cement limestone. These rocks may also be blended with dolomite from the Pinesburg Station or Tomstown Formations to produce a magnesium agricultural product. The limestones mapped in the Martinsburg Formation contain excessive amounts of acid-insoluble residue and are not suitable for any of the uses considered in this category. Fourteen randomly collected samples contained between 16 and 87 percent (median 28 percent) acid-insoluble residue.

A number of chemical analyses from various units are presented to quantify compositions typical of these rocks (Table 8). Samples 1 through 9, which are from the Shadygrove Formation, contain from 50 to 87 percent $CaCO_3$, 5 to 31 percent $MgCO_3$, and 2 to 16 percent SiO_2. Samples 10 through 19, from the Rockdale Run Formation, contain 77 to 90 percent $CaCO_3$, 1 to 24 percent $MgCO_3$, and 2 to 15 percent SiO_2. Samples 20 through 22, from the Chambersburg Formation, confirm the more uniform character of this argillaceous limestone, containing 75 to 81 percent $CaCO_3$, 3 to 4 percent $MgCO_3$, and 8 to 15 percent SiO_2.

Visual examination indicates that the Stoufferstown and Zullinger Formations, in gross aspect, contain more SiO_2 than the Rockdale Run Formation and that the Stonehenge Formation is compositionally similar to the Rockdale Run and the more calcareous portions of the Shadygrove. In general the chemical analyses confirm what is evident from acid-insoluble-residue content and petrology—that these rocks do not meet the specifications for high-calcium limestone.

LIMESTONE CHEMISTRY AND ACID-INSOLUBLE RESIDUES

Determination of the amount of acid-insoluble residue of carbonate rocks has been principally used for rapid discrimination between potential high-calcium limestone ($>95\%$ $CaCO_3$) and less pure limestones; however, this gives no determination of $MgCO_3$ present. $MgCO_3$ must therefore be analyzed by other techniques. From studies in Franklin and Cumberland Counties it appears that, in addition to measuring the total noncarbonate component of the rock, under certain conditions an approximation of the chemical composition of the acid-insoluble residue fraction can be determined.

Chemical analyses of carbonate rocks indicate that the acid-insoluble residue is normally composed of SiO_2, Al_2O_3, and Fe_2O_3. Usually P_2O_5 and S are reported in the chemical analyses, but as they frequently constitute less than 0.05 percent of the sample, they are disregarded for the procedure discussed here. The SiO_2, Al_2O_3, and Fe_2O_3 represent the terrigenous fraction (clay, quartz silt, and very fine quartz sand) in the carbonates. In an area where the terrigenous component is derived from a source terrain of somewhat uniform composition, the amounts of SiO_2, Al_2O_3, and Fe_2O_3 should bear a constant relation to one another.

Twenty analyses (Table 7) from limestones and dolomitic limestones of the St. Paul Group at the Hempt Bros. quarry, Lower Allen Township, Cumberland County, and 12 chemical analyses of St. Paul high-calcium limestone near Marion, Franklin County, demonstrate a constant relationship of $SiO_2:Al_2O_3:Fe_2O_3$. A plot of SiO_2 against $Al_2O_3 + Fe_2O_3$ (Figure 26a) shows that a linear relationship (visually derived) exists, and that from this linearity $SiO_2:Al_2O_3 + Fe_2O_3$ is 3.8:1. A second plot (Figure 26b) of Al_2O_3 against Fe_2O_3 also shows a linear relationship from which $Al_2O_3:Fe_2O_3$ is 3.2:1. This indicates that a typical acid-insoluble-residue sample from the St. Paul Group contains $SiO_2:Al_2O_3:Fe_2O_3$ in the proportion of 12.2:3.2:1 or, less precisely, 12:3:1. Thus, acid-insoluble residues can be used as a measure of noncarbonate major oxides, from which it is possible to designate the utility of limestone for industrial or chemical purposes.

Two factors should be considered which will affect the reliability of the concepts outlined. Secondary silicification, which introduces SiO_2 in the form of chert or quartz rosettes, is a fairly random process within the context of this study, and the oxide proportions may vary considerably from those established. Hence, any beds containing chert will give erroneous results and should be sampled with care. Wind-blown quartz grains, although primary in the sense that they accumulated during formation of the limestone, also introduce SiO_2 in a random manner; therefore, beds containing visible wind-blown quartz grains also will give erroneous results and should be sampled with care.

COARSE AGGREGATE

Material classed as coarse aggregate by the Pennsylvania Department of Transportation (PennDOT) includes stone, gravel, and slag, of which only stone is produced in the mapped area. Highway specifications state that stone, whether it be type A, B, or C, must be prepared from tough, durable rock, free from slaty texture or cleavage planes. Classification of stone is based primarily on weight loss during the Los Angeles Rattler test—the loss is progressively greater from type A to type C. In addition, more deleterious substances such as shale and clay lumps are permitted in type C than in type A stone.

In the mapped area type A stone is produced from the St. Paul Group and the Epler Formation. Other quarries in Cumberland County yielding type A stone produce from the Stonehenge, Rockdale Run, and Chambers-

Table 8. *Chemical Analyses of Various Cambro-Ordovician Limestones in Eastern Cumberland County*

TEST	1	2	3	4	5	6	7	8	9	10	11
SiO_2	2.14	3.59	5.73	6.26	13.2	9.83	16.4	5.17	5.41	5.08	12.5
Al_2O_3	.32	.80	.84	.80	1.73	.72	.55	.62	.72	.96	2.67
Fe_2O_3	.19	.23	.25	.26	.62	.30	.20	.56	.20	.74	1.01
P_2O_5	.06	.05	.07	.02	.11	.07	.06	.09	.02	.21	.03
MgO	5.18	3.42	4.28	1.70	14.9	8.39	4.46	5.39	2.48	1.53	2.49
($MgCO_3$) **	(10.82)	(7.15)	(8.95)	(3.55)	(31.14)	(17.53)	(9.32)	(11.26)	(5.18)	(6.12)	(5.20)
CaO	47.7	48.1	47.2	49.7	28.1	38.9	40.2	44.9	48.8	50.4	41.4
($CaCO_3$) ***	(84.91)	(85.62)	(84.02)	(88.46)	(50.02)	(69.24)	(71.55)	(79.92)	(86.86)	(89.96)	(73.69)
Total S, as SO_3	.01	.11	.02	.03	.09	.01	.16	.04	.05	.04	.16
Sulfate S, as SO_3	.01*	.11	.01	.01*	.07	.01	.03	.01*	.01	.01	.01*
Na_2O	.02	.01*	.01*	.02	.03	.02	.01	.13	.02	.01	.16
K_2O	.21	.36	.61	.53	.97	.48	.36	.38	.46	.62	1.58
Insoluble residue	3.51	4.75	7.11	8.08	18.70	11.03	18.74	6.92	6.74	7.06	17.66
Loss in ignition	43.22	42.46	41.41	40.71	38.53	40.49	36.40	41.67	41.17	40.58	35.67

TEST	12	13	14	15	16	17	18	19	20	21	22
SiO_2	10.2	3.8	2.2	4.5	6.6	8.0	8.3	8.0	8.70	11.0	15.1
Al_2O_3	2.14	0.3	0.2	0.5	1.0	1.4	1.2	1.0	1.45	2.23	3.35
Fe_2O_3	.93	0.87	0.19	0.15	0.28	0.29	0.58	0.24	.61	.99	1.24
P_2O_5	.15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	.13	.19	.21
MgO	.57	11.7	5.8	1.9	4.2	3.5	6.0	3.3	2.18	1.93	1.48
($MgCO_3$) **	(1.19)	(24.47)	(12.13)	(3.9)	(8.78)	(7.3)	(12.54)	(6.9)	(4.55)	(4.04)	(3.09)
CaO	46.5	43.1	48.7	50.8	47.4	47.0	44.9	47.2	45.5	45.2	42.5
($CaCO_3$) ***	(82.77)	(76.9)	(86.92)	(90.68)	(84.6)	(83.89)	(80.14)	(84.25)	(80.99)	(80.45)	(75.65)
Total S, as SO_3	.19	0.12	0.08	0.19	0.33	0.31	0.31	0.42	.03	.07	.06
Sulfate S, as SO_3	.02	0.08	0.07	0.15	0.10	0.08	0.09	0.13	.01	.02	.01
Na_2O	.10	0.01	0.01	0.02	0.05	0.05	0.06	0.03	.16	.17	.28
K_2O	1.47	0.22	0.17	0.30	0.50	0.82	0.58	0.48	.24	.59	.66
Insoluble residue	13.97	5.7	2.2	5.9	9.8	11.9	12.5	10.9	11.06	14.05	20.46
Loss in ignition	37.92	40.1	42.6	41.2	39.0	38.5	38.0	39.2	38.89	38.49	35.78

*Less than

**MgO calculated to $MgCO_3$ by gravimetric factor 2.0915

***CaO calculated to $CaCO_3$ by gravimetric factor 1.785

LOCATION OF SAMPLES

Sample 1. Collected from a section 120 ft thick in middle of Shadygrove Formation along Old Stonehouse Road just north of Trindle Springs Road (40°11′46″N/77°05′27″W); represents interval 0-10 ft at base of this incomplete section.

Sample 2. As previous, interval 10-20 ft.

Sample 3. As previous, interval 20-30 ft.

Sample 4. As previous, interval 30-40 ft.

Sample 5. As previous, interval 40-50 ft.

Sample 6. As previous, interval 50-60 ft.

Sample 7. As previous, interval 60-80 ft.

Sample 8. As previous, interval 80-100 ft.

Sample 9. As previous, interval 100-120 ft.

Sample 10. Rockdale Run Formation, interval 0-30 ft above base of quarry floor, Locust Point quarry, Mechanicsburg quadrangle.

Sample 11. As previous, interval 30-60 ft above quarry floor.

Sample 12. As previous, composite from stockpiles.

Sample 13. Rockdale Run Formation. 50-20 ft below top of measured section at Mechanicsburg Naval Supply Depot (40°14′30″N/77°00′02″W).

Sample 14. As previous, 20-0 ft below top.

Sample 15. Rockdale Run Formation, lower part of formation 0-75 ft above base of exposed partial section at Plainfield exit on Interstate 81 (40°11′06″N/77°14′00″W).

Sample 16. As previous, 75-135 ft above base of exposed partial section.

Sample 17. As previous, 135-195 ft above base of exposed partial section.

Sample 18. As previous, 195-255 ft above base of exposed partial section.

Sample 19. As previous, 255-350 ft above base of exposed partial section.

Sample 20. Chambersburg Formation, composite from stockpile at Silver Springs quarry, Mechanicsburg quadrangle.

Sample 21. Chambersburg Formation, interval 0-100 ft above base of Chambersburg at Sample Bridge section of Dyson (1967, p. 59-61).

Sample 22. As previous, interval 100-200 ft above base of Chambersburg.

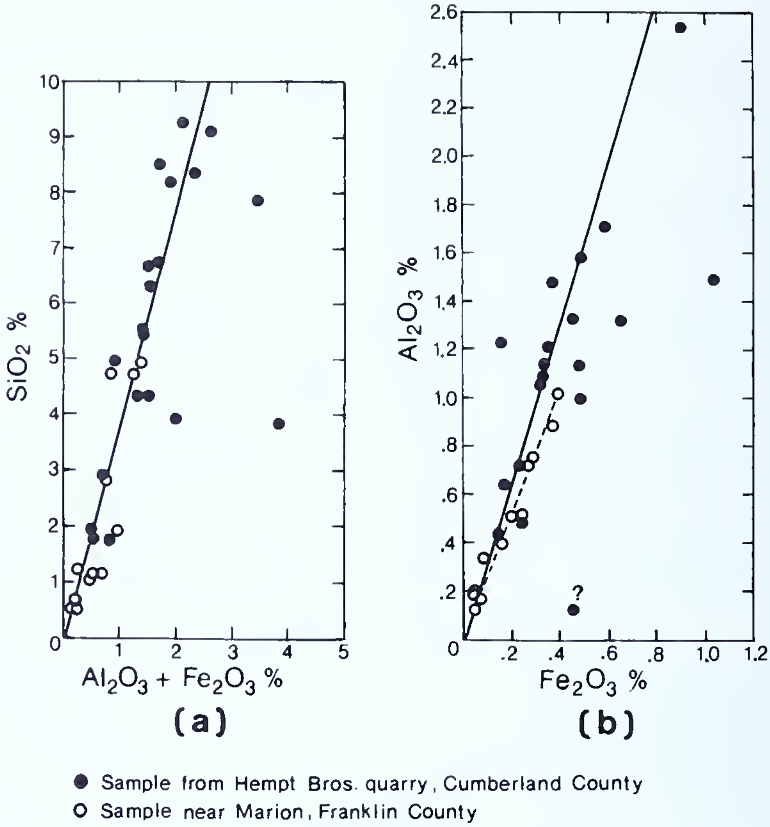


Figure 26. (a) Plot of $SiO_2:Al_2O_3 + Fe_2O_3$ from 32 chemical analyses of the St. Paul Group. Equation of line is SiO_2 tot. $= 2.9683 + 0.6827$ $Al_2O_3 + Fe_2O_3$. (b) Plot of $Al_2O_3:Fe_2O_3$ from same analyses as (a). Equation of major line is Al_2O_3 tot. $= 1.3199 + 0.9097$ Fe_2O_3. Equation of minor line is Al_2O_3 tot. $= 2.4467 + 0.0355$ Fe_2O_3.

burg Formations, and the Conococheague Group. Because of their grossly uniform lithology these units may be expected to yield type A stone throughout the county. From field observations the Pinesburg Station Formation, and possibly also the Stoufferstown Formation, should yield type A stone. Large quantities of type A stone can be produced from the diabase plutons. Other units in the area are not capable of producing type A stone because of thin bedding properties and/or a pervasive cleavage or limited extent.

FINE AGGREGATE

Material classed by the Pennsylvania Department of Transportation as fine aggregate for use other than in bituminous mixtures consists of hard, durable grains thoroughly cleaned by washing, and free from lumps of clay and all vegetable and deleterious substances. Three categories are recognized: natural sand, manufactured sand, and artificial sand. Some of the river and stream gravels and sands (Plate 1) are capable of yielding both fine and coarse aggregate, but to date they have not been prospected. Probably some of the Triassic sandstones can be mechanically disaggregated to fine aggregate, but extensive testing is required. Similarly some of the carbonate rocks can be crushed to fine-aggregate size to yield a suitable product, but cost is prohibitive.

DIMENSION STONE

Building stone, monumental stone, paving stone, curbing, and flagging are included under the category of dimension stone. Physical properties to be considered are hardness and workability, strength, porosity, specific gravity, and durability. Other factors to consider are textures and color, which influence the appearance of a rock. Utility of the rocks for dimension stone has been discussed by Stone (1932, p. 122-125 and 299-304). He cites the abundant local use of various limestones as building stone. In the writer's opinion many of the limestones have sufficient beauty and the physical requirements for a popular building stone of the ashlar* type.

The reddish to light-gray marbleoid limestones at the base of the Rockdale Run Formation (Plate 1) and certain reddish marbleoid limestone horizons in the Zullinger Formation offer possibilities for an attractive monument stone or building stone. From observations in quarries the marbleoid limestones of the Rockdale Run Formation maintain these colors at depths and, where free of chert nodules, are in sufficiently thick beds that large pieces could be quarried. Local shale intercalations at this horizon, however, may prove to be a problem in quarrying.

SHALES AND CLAY

Recent work by O'Neill and others (1965), Hoover and others (1971), and Root (1971) has indicated potential utility of the shales of the Martinsburg Formation in the Cumberland Valley. Because of this important economic aspect the Martinsburg shales were sampled and analyzed in the mapped area.

On the basis of slow-firing tests, physical properties such as workability, plasticity, pH and soluble salt determinations, water of plasticity, drying and firing shrinkage, color (fired and unfired), percent cracking, apparent specific gravity, and hardness determine whether a clay is suitable for ceramic or nonceramic uses. Included under the ceramic category are clays used for whiteware, structural products, refractory products, artware or pottery, and lightweight aggregate. Included under the nonceramic category are clays used as filler for paint, plastics, paper, rubber, and in oil clarifiers, abrasives, foundry molds, drilling muds, and pigments (O'Neill and others, 1965).

Sample 147-7-1 (Hoover and others, 1971), collected in East Pennsboro Township 0.2 mile (0.3 km) west of Enola on Pa. Route 944, had a potential use for outside pottery and fair-quality lightweight aggregate. Sample 148-1-2, collected in Upper Allen Township on U. S. Route 15 about 0.25 mile (0.4 km) south of the Pennsylvania Turnpike, had a potential use for fair-quality lightweight aggregate.

Ten additional samples were collected from the Martinsburg in the mapped area. Five samples (148-A-9 to 148-A-13) were collected from shales of the Lebanon Valley sequence on the Yellow Breeches thrust plate, and five samples (147-C-8 to 147-C-12) were collected from Martinsburg and allochthonous shales of the Cumberland Valley sequence. The samples were physically tested by Morse Laboratories. With regard to potential use there does not appear to be a difference in the shales of the two sequences. The shales of both sequences have potential use as brick and tile products, structural clay products including sewer pipe, and lightweight aggregate, which ranges in quality from fair to excellent. The location, test results, and potential use of each sample are listed in Appendix 4. These samples are only intended to indicate potential use of shales in the area; for purposes of exploitation detailed sampling and testing are mandatory.

The mineralogy and chemical composition of two samples of Martinsburg shale from the Cumberland Valley (147-7-1) and Lebanon Valley (148-1-2) sequences were analyzed by Hoover and others (1971). For comparative purposes one sample of Martinsburg shale was collected from the Lebanon Valley sequence in the mapped area near Bowmansdale (40°10′00″N/76°58′45″W) and analyzed by X-ray technique. The results are presented in Table 9. The mineralogical variation between the two samples from the Lebanon Valley sequence (148-1-2 and Bowmansdale samples) is so large that this technique appears to hold little promise as a tool by which to distinguish the two sequences. The Lebanon Valley sequence reflects a greater degree of metamorphism, as the micas are unusually well crystallized, whereas the micas from the Cumberland Valley sequence are fine-grained sericitic material not usually visible mesoscopically. The sample from Bowmansdale was not analyzed chemically, but the two samples collected by Hoover and others (1971) show a considerable uniformity of chemical composition. They contain 12 to 14 percent Al_2O_3, which is somewhat too low to be considered as a source of aluminum under present conditions of extraction and processing.

In addition to these data, some information is available on content of organic matter in the Martinsburg shales of the Cumberland Valley sequence. Two samples, collected by Baker and Claypool (1970) at the confluence of Conodoguinet Creek and the Susquehanna River, contain

Table 9. *Mineralogy and Chemical Analyses from the Martinsburg Formation*

Sample	147-7-1		148-1-2		Harrisburg West Area (Bowmansdale)	
			Mineralogy: X-ray			
	Percent	Accuracy (±)	Percent	Accuracy (±)	Percent	Accuracy (±)
Quartz	37	5	50	10	32	10
Mica	34	6	35	12	48	15
Kaolinite	10	7	0	—	6	6
C-V-Mo*	9	3	9	3	5	3
Feldspar	4	2	1	1	3	2
		Chemical Analysis				
	Percent		Percent			
SiO_2	67.60		68.30			
Al_2O_3	12.00		14.00			
Fe_2O_3	4.04		6.56			
FeO	0.18		—			
CaO	0.61		>0.05			
MgO	1.52		1.04			
K_2O	3.80		3.90			
Na_2O	1.26		0.51			
TiO_2	0.82		0.92			
L.O.I.	5.15		4.62			
S	0.04		>0.02			
CO_2	0.95		0.22			

*C-V-Mo = chlorite, vermiculite, montmorillonite.

only small amounts of hydrocarbon (organic carbon = 0.48% wt., hydrocarbon = 51 ppm, sat./arom. = 3.1, av. mol. wt. sat. = 245 + 10), partially a result of low-grade metamorphism, and cannot be considered as a potential source for hydrocarbon.

HYDROLOGY AND ENVIRONMENTAL GEOLOGY

The fundamental data of this report have been interpreted for planners, developers, and environmentalists by McGlade and Geyer (1976) in a companion publication entitled *Environmental Geology of the Greater Harrisburg Metropolitan Area.* A report on the ground-water resources of this area is in preparation as part of a general report on the hydrology of Cumberland County (Becher and others, in preparation).

Basic engineering and ground-water data are presented in abbreviated form on the legend accompanying the geologic map (Plate 1).

REFERENCES

Baker, D. P., and Claypool, G. E. (1970), *Effects of incipient metamorphism on organic matter in mudrock,* Am. Assoc. Petroleum Geologists Bull., v. 54, p. 456-468.

Becher, A. E., Root, S. I., and Weterhill, W. (in preparation), *Geology and ground-water resources of Cumberland County, Pennsylvania,* Pa. Geol. Survey, 4th ser., Water Resource Rept.

Bissell, M. H. (1921), *The Triassic area of the New Cumberland quadrangle (York County), Pennsylvania,* Ph.D. thesis, Yale Univ.

Carswell, L. D., Hollowell, J. R., and Platt, L. B. (1968), *Geology and hydrology of the Martinsburg Formation in Dauphin County, Pennsylvania,* Pa. Geol. Survey, 4th ser., Water Resource Rept. 24.

Cloos, Ernst (1947), *Oolite deformations in the South Mountain fold, Maryland,* Geol. Soc. America Bull., v. 58, p. 843-918.

Cloos, Ernst, and Broedel, C. H. (1943), *Reverse faulting north of Harrisburg, Pennsylvania,* Geol. Soc. America Bull., v. 54, p. 1375-1397.

Drake, A. A., Jr. (1970), *Structural geology of the Reading Prong,* in Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, K. N., eds., *Studies of Appalachian geology: central and southern,* p. 271-291, New York, Interscience Publishers.

Dyson, J. L. (1967), *Geology and mineral resources of the southern half of the New Bloomfield quadrangle, Pennsylvania,* Pa. Geol. Survey, 4th ser., Atlas 137cd.

Faill, R. T. (1973), *Tectonic development of the Triassic Newark-Gettysburg Basin in Pennsylvania,* Geol. Soc. America Bull., v. 84, p. 725-740.

Farrel, M. A., Sprague, H. B., and Higbee, H. W. (1956), *Soil map of Cumberland County, Pennsylvania,* Pa. State Univ., Agricultural Exp. Sta.

Flinn, Derek (1962), *On folding during three-dimensional progressive deformation,* Geol. Soc. London Quart. Jour., v. 118, p. 385-433.

Ghosh, S. K., and Ramberg, H. (1968), *Buckling experiments on intersecting fold patterns,* Tectonophysics, v. 5, p. 89-105.

Glaeser, J. D. (1971), *A possible sedimentologic analogue of the Triassic Newark-Gettysburg Basin—the northwest Gulf of California,* Geol. Soc. America Abs. with Programs, v. 3, p. 32-33.

Hoover, K. V., Saylor, T. E., Lapham, D. M., and Tyrell, M. E. (1971), *Properties and uses of Pennsylvania shales and clays, southeastern Pennsylvania,* Pa. Geol. Survey, 4th ser., Min. Resource Rept. 63.

Hotz, P. E. (1950), *Diamond-drill exploration of the Dillsburg magnetite deposits, York County, Pennsylvania,* U. S. Geol. Survey Bull. 969-A, p. 1-27.

Lesley, J. P. (1879), *Notes on a series of analyses of dolomitic limestone rocks of Cumberland County, Pennsylvania,* Pa. Geol. Survey, 2nd ser., Rept. MM, p. 311-362.

MacLachlan, D. B. (1967), *Structure and stratigraphy of the limestones and dolomites of Dauphin County, Pennsylvania,* Pa. Geol. Survey, 4th ser., Gen. Geology Rept. 44.

MacLachlan, D. B., and Root, S. I. (1966), *Comparative tectonics and stratigraphy of the Cumberland and Lebanon Valleys,* Guidebook, 31st Ann. Field Conf. Pa. Geologists, Pa. Geol. Survey.

McGlade, W. H., and Geyer, A. R. (1976), *Environmental geology of the greater Harrisburg metropolitan area,* Pa. Geol. Survey, 4th ser., Environ. Geology Rept. 4.

McLaughlin, D. B. (1961), *Some features of the Triassic north border in Pennsylvania,* Pa. Acad. Sci. Proc., v. 35, p. 124-128.

O'Neill, B. J., Jr., Lapham, D. M., Jaron, M. G., Socolow, A. A., Thomson, R. D., and Hamlin, H. P. (1965), *Properties and uses of Pennsylvania shales and clays,* Pa. Geol. Survey, 4th ser., Min. Resource Rept. 51.

Pierce, K. L. (1966), *Bedrock and surficial geology of the McConnellsburg quadrangle, Pennsylvania,* Pa. Geol. Survey, 4th ser., Atlas 109a.

Platt, L. B., Loring, R. B., Papaspyros, Anthanasios, and Stephens, G. C. (1972), *The Hamburg klippe reconsidered,* Am. Jour. Sci., v. 272, p. 305-318.

Prouty, C. E. (1960), *Carbonate rocks in eastern Pennsylvania,* in Gates, Olcott, ed., *Lower Paleozoic carbonate rocks in Maryland and Pennsylvania,* Johns Hopkins Univ. Studies Geology, no. 18, p. 61-101.

Root, S. I. (1968), *Geology and mineral resources of southeastern Franklin County, Pennsylvania,* Pa. Geol. Survey, 4th ser., Atlas 119cd.

——— (1970), *Structure of the northern terminus of the Blue Ridge in Pennsylvania,* Geol. Soc. America Bull., v. 81, p. 815-830.

——— (1971), *Geology and mineral resources of northeastern Franklin County, Pennsylvania,* Pa. Geol. Survey, 4th ser., Atlas 119ab.

——— (1973), *Sequence of faulting, southern Great Valley, Pennsylvania,* Am. Jour. Sci., v. 273, p. 97-112.

Rose, A. W. (1972), *Favorability for Cornwall-type magnetite deposits in Pennsylvania using geological, geochemical, and geophysical data in a discriminant function,* Jour. Geochemical Exploration, v. 1, p. 181-194.

Smith, R. C., II (1973), *Geochemistry of Triassic diabase in southeastern Pennsylvania,* unpub. Ph.D. thesis, Pa. State Univ.

Smith, R. C., II, Rose, A. W., and Lanning, R. M. (1975), *Geology and geochemistry of Triassic diabase in Pennsylvania,* Geol. Soc. America Bull., v. 86, p. 943-955.

Stone, R. W. (1932), *Building stones of Pennsylvania,* Pa. Geol. Survey, 4th ser., Min. Resource Rept. 15.

Stose, G. W. (1930), *Unconformity at the base of the Silurian in southeastern Pennsylvania,* Geol. Soc. America Bull., v. 41, p. 629-657.

——— (1932), *Geology and mineral resources of Adams County, Pennsylvania,* Pa. Geol. Survey, 4th ser., County Rept. 1.

——— (1946), *The Taconic Sequence in Pennsylvania,* Am. Jour. Sci., v. 244, p. 665-696.

——— (1949), *The fault at the west edge of the Triassic in southern Pennsylvania,* Am. Jour. Sci., v. 247, p. 531-536.

Stose, G. W. (1953), *Geology of the Carlisle quadrangle, Pennsylvania,* U. S. Geol. Survey Geol. Quad. Map GQ 28.

Stose, G. W., and Jonas, A. I. (1939), *Geology and mineral resources of York County, Pennsylvania,* Pa. Geol. Survey, 4th ser., County Rept. 67.

Tobisch, O. T., and Glover, Lynn, III (1971), *Nappe formation in part of the southern Appalachian piedmont,* Geol. Soc. America Bull., v. 82, p. 2209-2230.

Zen, E-an (1972), *The Taconide zone and the Taconic orogeny in the western part of the northern Appalachians,* Geol. Soc. America Spec. Paper 135.

GLOSSARY

a, ac, b, ab. Reference orthogonal axes of folds: *b* parallels fold axis; the *ac* plane contains *a* and *c,* is normal to *b,* contains the movement direction, and is a plane of bilateral symmetry normal to the fold hinge; *ab* is the plane parallel to the fold hinge.

Algal mat. Finely laminated rock of shallow-water or tidal origin, usually limestone or dolomite, composed of material trapped and formed by algae living in mat-like colonies.

Allochthonous. Said of a rock derived from an environment other than that in which it is found.

Alluvial. A term referring to clay, silt, sand, and gravel deposited by a stream or running water.

Anisotropy. A condition in which physical properties vary in different directions.

Antiformal. An anticlinal structure in which the stratigraphic sequence is not known.

Antithetic faults. A system of nearly parallel normal faults involving rotation of bedding.

Argillaceous. Composed of clay minerals (refers to a sedimentary rock).

Ashlar. A thin, squared and dressed stone used for facing a wall of rubble or brick.

Autochthonous. Said of a rock derived in the place where it is now found.

$B \perp B'$ folds. Syngenetic folds perpendicular to the regional fold axis. Strictly speaking, the reclined folds of this investigation are not syngenetic but reoriented.

Bioturbated. Churned and stirred by organisms (when the rock was an unconsolidated sediment).

Bouma cycle. A fixed succession of five intervals that make up a complete sequence of turbidite.

Boudinage. An originally continuous layer that has been stretched, thinned, and broken at regular intervals.

Carbonate. A sedimentary rock deposited by organic or inorganic precipitation of carbonates of calcium (limestone) and magnesium (dolomite) from aqueous solution; usually contains grains of preexisting carbonate rock or shell material.

Clast. An individual grain or fragment of a rock produced by disintegration of a larger rock mass.

Colluvium. Loose, incoherent mass of soil and rock material deposited by mass wasting at bases of steep slopes.

Detrital limestone. A limestone composed primarily of particles or fragments derived from preexisting rocks either by erosion or weathering.

Diabase. An intrusive igneous rock that has ophitic texture and is composed of crystals of feldspar and pyroxene.

Distal turbidite. A sedimentary deposit consisting of fine, graded clastics formed farthest from the source area.

Domain. An area in which bedding or other defined attributes are uniform.

Edgewise conglomerate. An intraformational conglomerate in which tabular fragments are steeply inclined to bedding.

Fracture trace. A natural linear feature, less than a mile in length, consisting of topographic, vegetation, or soil tonal alignments visible principally on aerial photographs.

Graywacke. A tough, dark-colored, coarse-grained sandstone composed of poorly sorted grains of quartz, feldspar, and rock fragments in a clayey matrix.

Great circle. A stereographic projection of a plane passing through the center of a reference sphere.

Hinge. The point of maximum curvature or bending of a fold.

Interlimb angle. The angle between limbs of a fold.

Intraformational conglomerate. A conglomerate in which the clasts are essentially contemporaneous in origin with the matrix and derived from nearby, partly consolidated, similar rock.

Kink band. A tabular zone along which bedding is deflected; in the study area kink bands are usually part of a conjugate fold system.

Klippe. An isolated rock mass that is an erosional remnant of a more extensive thrust sheet.

Mélange. A mappable body of deformed rocks consisting of a pervasively sheared, fine-grained, argillaceous matrix thoroughly mixed with angular and poorly sorted inclusions of native and exotic tectonic fragments.

Mesoscopic. A term used to describe a tectonic feature large enough to be observed without a microscope yet small enough to be observed in its entirety.

Metabentonite. A dense, light-colored rock composed of clay minerals that formed by alteration of a volcanic ash bed; contains feldspars and zircons.

Micrite. A semiopaque crystalline matrix of limestones consisting of crystals generally 1 to 3 microns.

Micrograined. A grain size in carbonate rocks comparable to silt size in quartzose sediments.

Nappe. A sheetlike, allochthonous rock mass of regional extent.

Necking direction. Direction of the trace of attenuation of boudinaged beds.

Oolitic limestone. A sedimentary rock composed of small, round accretionary bodies developed under shallow marine conditions; frequently pellets and detrital grains are associated.

Paraklippe. A thrust sheet which has only the frontal part resting on rocks of different facies.

Peritidal. Said of that part of the seashore near the tidal range.

Pi diagram. Projection of poles of normals to bedding onto the lower hemisphere of an equal-area stereonet. A great circle is defined, the pole of which is the π-axis (plunge of folded bedding).

Quartz normative tholeiite. A rock of basaltic composition composed of the minerals labradorite, clinopyroxene, and minor iron-titanium oxides set in a quartz-alkali feldspar matrix; contains little or no olivine.

Reclined folds. Isoclinal inclined folds with hinge lines that have a pitch greater than 80° on the axial surface. Most of the folds in the mapped area termed reclined actually are not quite true reclined folds.

Sabkha. A salt flat or low salt-encrusted plain restricted to a coastal area.

Skeletal limestone. A limestone consisting primarily of fauna or floral fragments that are not in their place of origin.

Streaking lineations. A number of features, such as mineral elongation, development of mineral trains, fine grooving on cleavage, or transposed bedding, that indicate movement of a rock mass.

Stromatolite. Variously domal-shaped, laminated, calcareous sedimentary structures formed in a shallow marine environment under the influence of a mat of algal origin.

Structural fabric. The sum of all structural and textural features of a rock.

Supratidal. Said of the area on the seashore just above mean high tide.

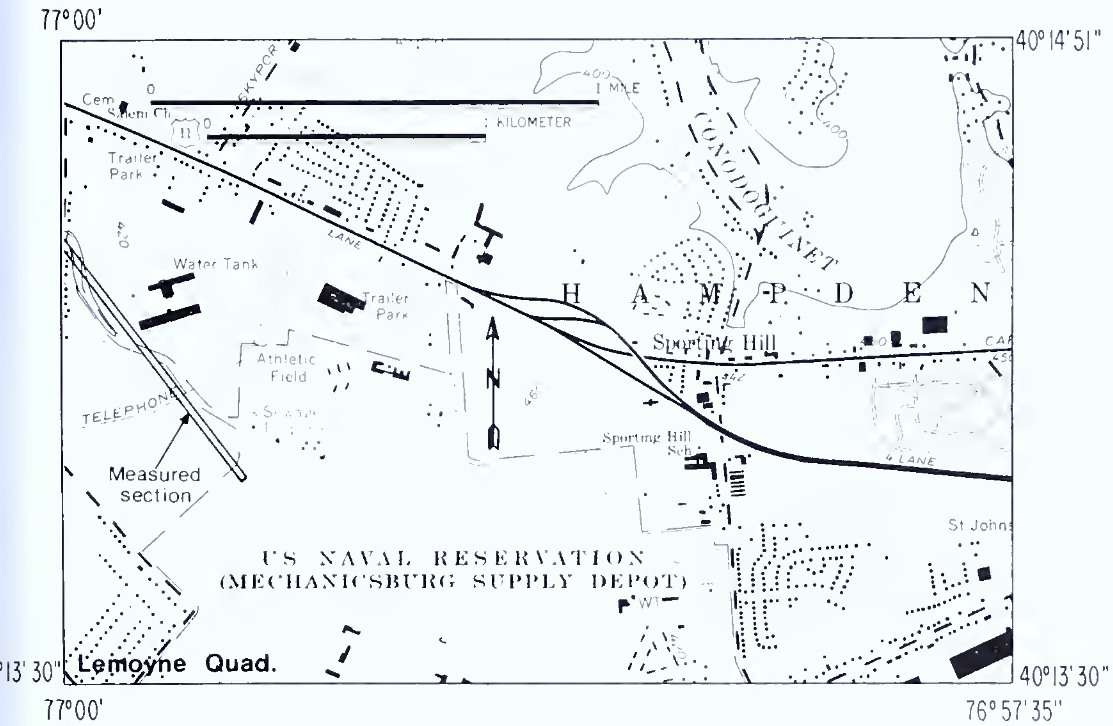
Synformal. A synclinal structure in which the stratigraphic sequence is not known.

Tectonite. A rock whose fabric clearly displays coordinated geometric features indicative of solid flow during deformation.

Vergence. The direction of overturning or of inclination of a fold.

APPENDIX 1

MEASURED SECTION IN PART OF THE CHAMBERSBURG FORMATION, THE ST. PAUL GROUP, AND PART OF THE BEEKMANTOWN GROUP



Unit		*Thickness (feet)*
	Chambersburg Formation (60.0 feet (18.3 m)—incomplete)	
78	Limestone, medium-dark-gray, semi-micritic with abundant fine to medium detrital and skeletal grains. Wispy dolomitic shaly laminae and bands give cobbly habit to rock. Locally has fetid odor and knotty weathered surface. About 30 percent exposed.	60.0
	St. Paul Group (581.0 feet (177.1 m)—complete)	
77	Covered interval.	80.0
76	Limestone, light-blue-gray, micritic with sparse clear calcite-spar "birdseye" structure.	3.0
75	Covered interval.	50.0
74	Limestone, light-medium-gray, micritic with fine clear calcite-spar "birdseye" structure.	8.0
73	Covered interval.	16.0
72	Gnarly limestone with minor interbands of dolomite, similar to unit 68 except that limestone bands are fine detrital-skeletal. Limestone bands ½ to 1 in., but lozenge shaped and darker colored than unit 68. Dolomite is in wispy bands and laminae.	36.0
71	Covered interval.	12.0
70	Similar to unit 68.	5.0
69	Covered interval.	29.0

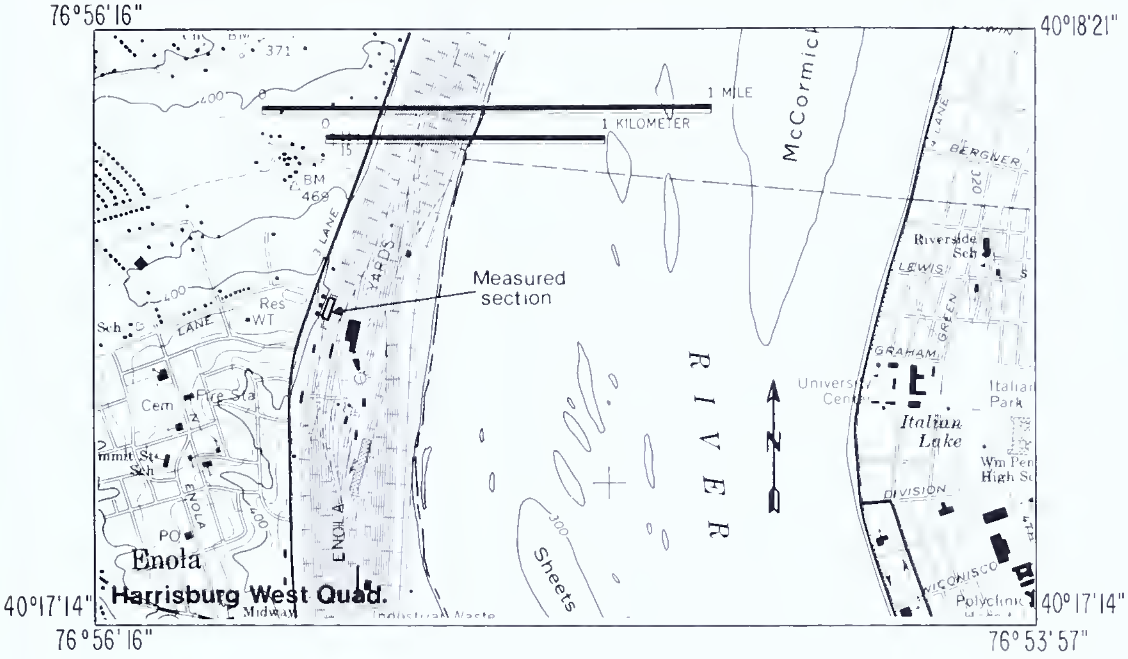
Unit		*Thickness (feet)*
68	Burrowed, interbanded limestone and dolomite. Limestone forms 70 percent of unit, in bands ¼ to 2 in.; dolomite in bands ⅛ to 1 in. Appears to have been originally planar interbanded, but it has all been burrowed to some extent, and locally original structure is completely destroyed; some 2-in. beds of micritic limestone with fine calcite spar "birdseye." Abundant nodules of black chert throughout.	25.0
67	Covered interval.	20.0
66	Dolomite, weathers light buff gray with some bands of slightly darker buff gray; very finely laminated, has some wispy discontinuous laminae, but mostly planar, continuous laminae; locally mud cracked. In 3-ft beds with thick limestone bands in poorly exposed intervals. Large stylolites on bedding. Sparse black chert nodules at top.	8.0
65	Limestone, similar to unit 57.	1.5
64	Dolomite, weathers light buff gray; fine planar laminations with some ripple structure.	2.0
63	Limestone, micritic, with large clear calcite-spar "birdseyes."	2.0
62	Banded limestone, similar to unit 57.	15.0
61	Covered interval.	7.0
60	Detrital limestone, medium to coarse grained; in planar beds 1 to 2 ft thick with sharp planar bases. A few inches above base some beds are burrowed and have a partially dolomitic matrix. Some thick unburrowed detrital limestone beds contained ½-in. rounded (oncolite?) dolomitic limestone clasts and tabular clasts to 1½ in.	10.0
59	Burrowed interbanded limestone and dolomite. Limestone, medium-blue-gray, semi-micritic to calcisiltite with abundant fine skeletal fragments, locally with large brachiopods; in 2- to 4-in. bands. Dolomite, weathers muddy buff gray, planar-laminated but burrowed, some large brachiopod valves; in 1- to 2-in. bands. Abundant black chert nodules to 8 in. long.	30.5
58	Covered interval.	37.0
57	Banded limestone, medium-blue-gray, calcisiltite with abundant fine skeletal material and a few large fossils such as 6-in. orthocerid on bedding surface; in bands of 2 to 4 in. Separated by ⅛-in. bands of yellow-buff argillaceous dolomitic limestone. Banding is semiplanar to "boudinage."	103.0
56	Similar to unit 54.	5.0
55	Similar to unit 53.	2.5
54	"Birdseye" limestone, light-blue-gray with distinctive whitish-gray weathering; mostly with network of coarse calcite-spar "birdseye," but locally network is fine.	15.0
53	Banded limestone, very light blue gray, with intervening laminae to thin bands of dolomite. Limestone bands are mud cracked and disturbed by stylolites and flow cleavage so that a pseudo-detrital or burrowed aspect is imparted. A few 6-in. dolomite beds near base contain limestone clasts, skeletal material, and bands.	11.5
52	Dolomite, similar to unit 50.	4.0
51	Detrital limestone, partially burrowed, with clasts to ¼ in. and large fossil fragments; locally matrix contains patches of dolomite and dolomite clasts.	1.5

Unit		*Thickness (feet)*
50	Dolomite, medium-buff-gray, massive.	6.5
49	Micritic "birdseye" limestone, light-blue-gray; 1- to 3-ft beds of micritic limestone, with *Maclurites* and other large fossils as clear to milky calcite spar, also large irregular patches of clear calcite spar. Some 1- to 3-ft interbeds of micritic limestone with an irregular network of small patches of calcite spar and locally small sparry fossil fragments and lenses of pebble-sized clasts; these appear to form vague stromatolites. Rocks grade into each other along strike.	35.0
Beekmantown Group (complete Pinesburg Station Formation, partial Rockdale Run Formation)		
	Pinesburg Station Formation (208.0 feet (63.4 m) thick)	
48	Dolomite, similar to unit 22 with 2-ft interbed of dolomite similar to unit 21. In many instances dolomites of types in units 21 and 22 cannot be distinguished and appear merely to be a function of weathering.	17.5
47	Dolomite, similar to unit 21, with a 2-ft interbed of dolomite similar to unit 22.	53.0
46	Dolomite, similar to unit 22.	1.5
45	Dolomite, similar to unit 21.	1.0
44	Dolomite, similar to unit 22.	4.5
43	Dolomite, similar to unit 21.	5.5
42	Dolomite, similar to unit 22, but in 2- to 6-in. beds.	5.0
41	Dolomite, similar to unit 21.	3.0
40	Limestone, medium-blue-gray with "muddy" hue, calcisiltite, finely laminated, in platy 1- to 3-in. beds.	3.0
39	Dolomite, similar to unit 21.	3.0
38	Covered interval.	5.0
37	Dolomite, similar to unit 22.	1.0
36	Dolomite, similar to unit 21.	8.0
35	Covered interval.	11.0
34	Dolomite, similar to unit 32.	1.0
33	Covered interval.	3.0
32	Dolomite, light-medium-gray, finely laminated.	2.0
31	Covered interval.	3.0
30	Dolomite, medium-gray with muddy hue, finely laminated.	1.0
29	Covered interval.	3.0
28	Dolomite, similar to unit 21, with a bed of dark dolomite.	11.0
27	Limestone, similar to unit 25.	1.0
26	Dolomite, similar to unit 21, but with black chert nodules to 1½ ft along bedding.	20.0
25	Limestone, medium-blue-gray, with semiplanar laminae of buff dolomite at ½-in. intervals.	1.0
24	Dolomite, similar to unit 21.	13.0
23	Dolomite, similar to unit 21.	21.0
22	Dolomite, light-medium-gray with muddy-buff cast, faintly laminated.	1.5
21	Dolomite, light-buff-gray, with bands of slightly darker dolomite that give sparse banded aspect to rock; bands ½ to 1½ in. Abundant gashed fractures, fetid odor, sparse tiny blebs of white chert.	4.5
	Rockdale Run Formation (195.0 feet (59.4 m), incomplete)	
20	Covered interval.	74.3

Unit		*Thickness (feet)*
19	Dolomite, similar to unit 14 (?outcrop).	1.0
18	Limestone, similar to unit 4.	4.0
17	Covered interval.	37.0
16	Limestone, similar to unit 7.	2.0
15	Burrowed limestone, similar to unit 4.	2.0
14	Dolomite, medium-buff-gray, finely laminated; with 1- to 4-in. pods and bands of limestone near base. In 6- to 12-in. beds; fetid odor; chert nodules to 4 in.	5.0
13	Limestone, similar to unit 7, some large snail shells.	5.0
12	Dolomite, light-orange-buff, very finely laminated in 8-in. beds.	3.5
11	Interlaminated to interbanded limestone and dolomite. Limestone, light-blue-gray, semi-micritic to calcisiltite, crossbedded. Dolomite, light-buff-gray.	1.7
10	Dolomite, buff, massive.	2.5
9	Limestone, light-blue-gray, semi-micritic, with sparse amounts of fine detrital and skeletal material; sparse dolomite laminae and bands; locally it is a pure micritic limestone.	7.0
8	Covered interval.	22.0
7	Limestone, light-blue-gray, with abundant interbands and laminae of dolomite that locally are burrowed and "churned" so that primary structure is destroyed. Dolomite is medium gray. Abundant white rosette blebs and nodules throughout.	6.5
6	Limestone, blue-gray, sparse fine detrital and skeletal material in micritic to calcisiltite matrix. Abundant bands of buff dolomite that are burrowed, with limestone churned into the burrows. Fetid odor; in beds 2 to 6 in.	5.5
5	Dolomite, "muddy"-grayish-buff; sparse laminations and banding.	3.5
4	Burrowed limestone and dolomite, original interbanding destroyed, and rock has a gnarly aspect due to thorough burrowing. Limestone is blue gray and locally very finely skeletal to detrital. Dolomite is buff.	3.0
3	Dolomite, "muddy"-gray, massive, highly gashed fractures; some white rosettes to 1 in.	3.0
2	Interbanded limestone and dolomite. In irregular ¼- to 1-in. bands, partially burrowed. Limestone is blue gray, dolomite is buff. Sparse tiny white rosettes.	2.5
1	Limestone, light-blue-gray to light-gray, detrital to skeletal with clasts to ¾ in. Some 2- to 4-in. micritic bands with sparse fossils. Some 2- to 4-in. bands with abundant irregular argillaceous laminae. In 1-ft beds.	4.0

APPENDIX 2

MEASURED SECTION IN THE SUMMERDALE ALLOCHTHON



Unit		(feet)
	Summerdale allochthon, sequence of carbonate rocks (151 feet (46 m) thick)	
	This allochthonous mass is limited by faults above and below.	
5	Interbanded buff-weathering limestone and dark-gray shaly arenaceous limestone. Beds are not planar but anastomose, producing appearance of very elongate limestone lenses. Limestone in bands 1 to 2 in. thick; locally, in lower part of unit, quartz-sized silt to fine grained, in thin layers that show crossbedding. Shaly arenaceous limestone is in bands 1 to 2 in. thick. In upper part of unit abundance of quartz grains decreases.	60
4	Thick-bedded arenaceous limestones composed of light- to medium-gray limestone with abundant layers 1 to 2 ft thick, containing coarse rounded floating quartz grains. A few beds of blue calcareous cross-bedded quartzitic sandstone occur. There are a few beds of conglomeratic limestone with limestone intraclasts to 4 in. and abundant quartz grains throughout the dark-gray calcareous matrix. A few beds 1 to 2 ft thick of thin-bedded limestone with dark-gray shaly bands are also present.	35
3	Thin-banded limestone interbedded with buff-weathering calcareous shale laminae.	3
2	Light, buff-weathering limestone in beds 1 ft thick with sparse to abundant, medium- to coarse-grained quartz as single layers or floating throughout. Locally crossbedded with 1- to 2-in.-thick calcareous shaly partings.	30
1	Buff, gray-weathering limestone in 1- to 2-in. bands. Locally cross-bedding is shown by layers of quartz grains, with 1- to 2-in. interbands of buff-weathering calcareous sandstone.	23

APPENDIX 3

DETAILED STRUCTURAL GEOLOGY

by

D. B. MacLachlan and S. I. Root

Appendix 3-A

The seventeen observations of slickensides recorded in the Yellow Breeches klippe (Figure 27c) indicate two directions, and hence two episodes, of movement. The set trending just east of north and west of south is approximately subnormal to the regional strike and closer to perpendicular to the local mean fold axis. These slickensides are quite plausibly related to the main (S_2) folding stress in the manner described for the younger rocks from Rockville to Amity Hall by Cloos and Broedel (1943), and are shown as open triangles designated L_2A on Figure 27c. The northwest-southeast-trending set is nearly parallel to fold axes that have obviously been reoriented, and was presumably produced by the same movements reorienting the folds. The trend and scatter of these slickensides is quite comparable to that observed for streaking lineations associated with the Yellow Breeches thrust, and it seems likely that they are related to the same deformational episode. These are shown as solid triangles, L_3, on Figure 27c. Associated with these faults are numerous extension veins filled with fibrous calcite. The relation of this faulting and veining to possible D_3 movement merits study.

Appendix 3-B

The gross orientations of folds in the Martinsburg are summarized in three pi diagrams that include the entire mapped area (Figure 28). The basal Martinsburg limestone (Ombl of Plate 1) fabric defines folding that plunges 081/16° (Figure 28a). The diagram from the mixed-terrain area (Figure 28b) defines a diffuse girdle with folds plunging 098/32°. Within the Enola allochthon in the belt of platy limestone and red beds (Omeal and Omear of Plate 1) the pi diagram (Figure 28c) forms an extremely diffuse girdle with folds plunging 065/12°. Although all folds regionally defined on the pi diagrams plunge east, the diffuse girdles are a clue that the actual deformational history is more complex than might be surmised at first approximation.

A considerable body of data indicates that there has been reorientation of Martinsburg folds subsequent to South Mountain (D_2) deformation. Comparative analysis of Martinsburg folds from the Harrisburg area with folds in the adjacent carbonate rocks as well as folds in the Martinsburg about 20 miles west in the Plainfield area substantiate this premise.

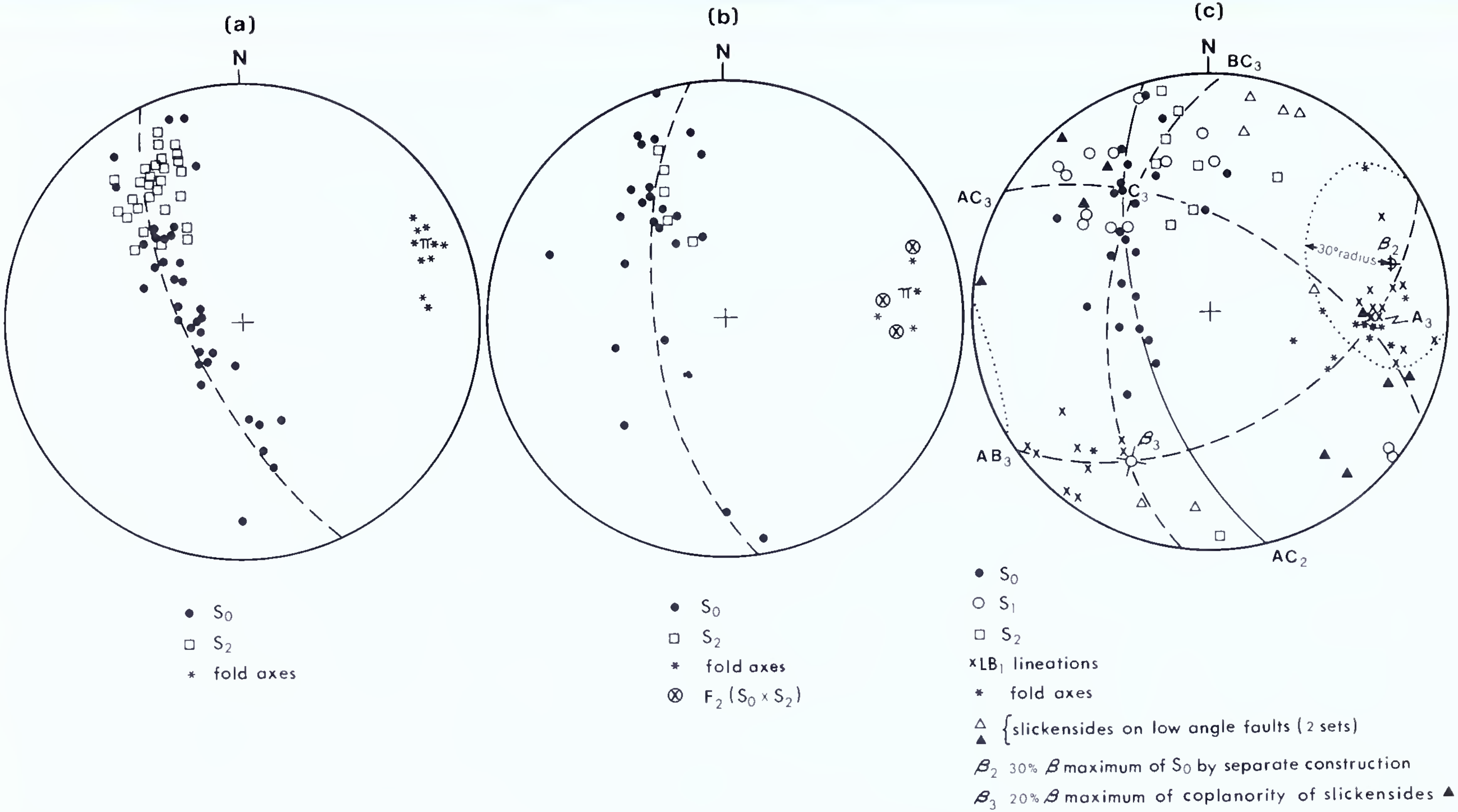
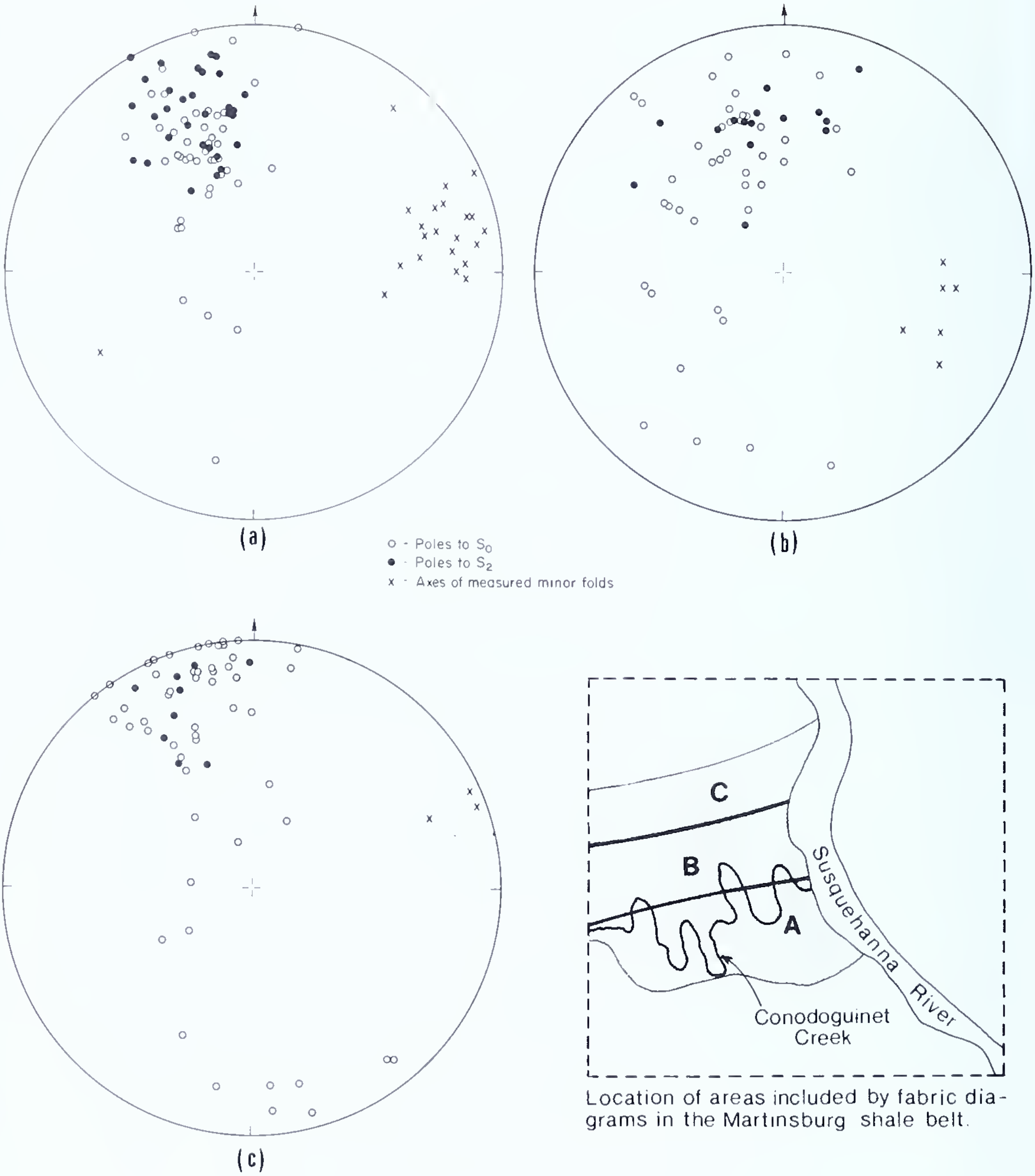


Figure 27. (a) Pi diagram and cleavage poles of Martinsburg Formation at extreme east edge of Plainfield quadrangle, along Conodoguinet Creek.

(b) Pi diagram and cleavage poles of basal limestones in the Martinsburg Formation at Sporting Hill Road along Conodoguinet Creek. Figure 8 shows same locality.

(c) Multiple deformations shown by pi diagram and cleavage poles of Yellow Breeches klippe at Penn Central Railroad cuts at confluence of Susquehanna River and Conodoguinet Creek. Solid line represents deformation plane (AC_2) of second deformation. Dashed lines represent principal planes of third deformation.



Location of areas included by fabric diagrams in the Martinsburg shale belt.

Figure 28. Pi diagram and cleavage poles of Martinsburg Formation in Cumberland Valley. Inset map shows location of areas a-c.

In the Plainfield area a series of excellent exposures along the Conodoguinet Creek at the extreme east edge of the quadrangle show a number of folds, some with kink-band geometries, that have interlimb angles of 120° to 130° and plunge 066/16°. S_2 has a polar distribution centered on the pi great circle (Figure 27a). The great circle is sharply defined by S_0 poles with small scatter. This bears considerable geometric affinity to the pi diagram of carbonate rocks in the Salem Church anticline along the west edge of the Harrisburg map area (Plate 1). The Salem Church structure (Figure 16) trends slightly more easterly because of regional variation, but has a similar plunge (076/16°), and is more appressed (interlimb angle of 70°).

At the intersection of Conodoguinet Creek and Sporting Hill Road, on the Salem Church anticline, basal Martinsburg beds differ geometrically from carbonate rocks within the core of the fold. The Martinsburg beds show a considerable amount of nearly isoclinal folding (Figure 8) with overturned limbs locally transposed in S_2, are considerably more appressed (interlimb angle of less than 40°), and plunge more steeply (082/24°) than the underlying carbonate rocks. The pi great circle is not as well defined (Figure 27b) as in the structurally lower carbonates (Figure 16). The difference in fold style here compared with that in the structurally lower carbonate-rock folds or more westerly Martinsburg folds at Plainfield suggests a more extended deformational history. It is not clear from Figure 27b that any significant reorientation of the deformational field has occurred, although the appreciable scatter of observed fold axes suggests this possibility. That the scatter of B_2 axes is the product of reorientation during D_3 seems probable on the basis of more clear-cut evidence described below.

On the Yellow Breeches klippe extensive exposures of shales and graywackes in the Penn Central Railroad cut near the confluence of Conodoguinet Creek and the Susquehanna River are structurally much more complex than the previous examples. Two cleavages may be readily identified in parts of the exposure, the younger most commonly as crenulations on the slaty cleavage partings. It is not immediately apparent what the relationship of these cleavages is to deformational events recognized elsewhere in the area.

The stereogram (Figure 27c) shows the slaty cleavage more scattered but centered at about the same position as the South Mountain cleavage (S_2) of Figures 27a and 27b. This cleavage fits poorly with observed fold axes, however, and from the diagram alone there is strong basis for the inference that this cleavage has been reoriented and that the sporadic second cleavage is the South Mountain cleavage developed where the antecedent cleavage was locally oriented unfavorably for the second deformation. This relationship is more directly displayed in similar rocks on Center Street (Figure 29), where the second cleavage is much more prominent. The clear implication is that, unlike other Martinsburg Formation exposures previously described, these rocks contained a cleavage (and folds) prior to the South Mountain deformation. This older cleavage, not present in underlying shales, strongly supports the inference that this graywacke sequence is allochthonous and that the cleavage was developed prior to or during emplacement. The simplest explanation is that the older cleavage was developed at the same time as the first cleavage in carbonate rocks of the Lebanon Valley nappe, but this cannot be definitely established from the local relationships.

The complex triclinic fabric of Figure 27c might appear to defy analysis; but, within constraints derived from external data and the

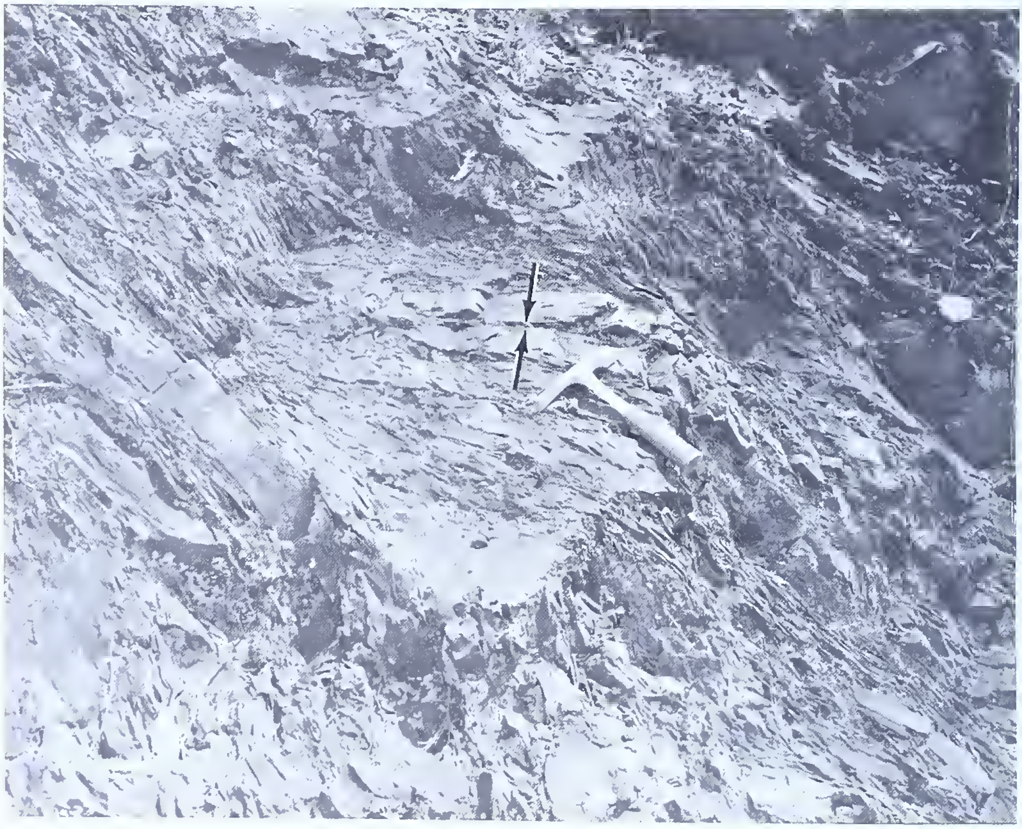


Figure 29. Allochthonous Martinsburg shales and graywacke in roadcut on Center Street along Conodoguinet Creek. Recumbent isoclinal fold is synclinal as indicated by graywacke grading (inset arrows); southward vergence suggests gross inversion of enclosing strata. Cleavage associated with isoclinal folding, probably same as F_1 of early nappes present on the Yellow Breeches thrust sheet, is present but not prominent in this exposure. Conspicuous cleavage, S_2, aligned with hammer handle, cuts both limbs and axial surface of fold without deflection.

mechanical properties of the rocks, it can be shown to be the product of three distinct episodes of deformation which can be more or less completely characterized.

Though it is not apparent in the distribution of bedding (S_0) poles in the diagram, which was biased by emphasizing collection of bedding data in the vicinity of hinges of the most prominent folds of graywacke beds, folds in this exposure are tight to nearly isoclinal, and the bedding throughout most of the crop dips fairly steeply southeastward, subparallel to the cleavage (S_1). A random statistical sample of bedding orientations would show an S_0 distribution much like that of S_1 with the (significant) girdle of this diagram much obscured. At any given point in the exposure where both can be conveniently determined, there is generally good agreement between S_0-S_1 intersections (B lineations of Figure 27c) and measured minor fold axes. This shows the folds have originated in the S_1 generating deformation (D_1), though they may have been tightened as well as reoriented by subsequent events. This relationship is the same as that shown directly on Center Street (Figure 29).

Owing to subsequent reorientation, the original attitude of B_1 cannot be precisely specified. If it is indeed the product of the same deformational event producing early cleavage in the nappes, a generally ENE-WSW trend may be anticipated. For mechanical reasons discussed below, the B_1 axis must have, in any case, lain within the small circle of 30° radius about B_2. This constraint provides a limit of uncertainty to the original B_1 orientation, which is fully consistent with the attitude expected from nappe deformation and tends to reinforce the inference that these structures and the nappe folds have a common origin.

The rocks of this exposure lie within a sequence that has obviously been strongly folded during the South Mountain event (D_2), and there is no doubt that these rocks have been comparably affected. In the absence of the early deformation the rocks here would have been much like those in the Plainfield area (Figure 27a) and would presumably have shown a comparable deformation. There is some indication that total deformation within the Martinsburg Formation and associated rocks increases eastward across the mapped area, but this is probably not an effect of the South Mountain (D_2) deformation. Inasmuch as this area lies somewhat structurally higher in the northeast-plunging South Mountain anticlinorium, the intensity of D_2 deformation may be expected to decrease in this direction, if any significant change occurs at all. Given the existence of antecedent folds, the geometry consequent to the superimposed deformation can be predicted a priori only if more variables can be established by independent criteria than is usually possible in field investigations. Theoretical and empirical investigations, however, provide constraints on interpretation of resultant structures which often allow the effective processes to be deduced. In Figure 27c there is a distinct girdle of S_0. The data are sufficiently diffuse that there might be some ambiguity to a visual best fit, but a β construction provides a very sharp maximum (β_2) corresponding to the rotation axis of this girdle. The fitted girdle ($\overline{AC}_2$) is the deformation plane perpendicular to the rotation axis as defined by β_2. For reasons to be elucidated in discussion of D_3, B_2 lies in the field of, but somewhat removed from, the maximum concentration of measured minor fold axes and bedding-cleavage (S_1) intersections (B lineations of diagram). It was previously noted that all of these folds evidently originate in D_1. The effect of D_2 is thus to reorient the preexisting folds. Given the high competence contrast between the shales and the graywackes and known conditions of deformation in comparable rocks without D_1 impress at Plainfield, it may be confidently stipulated that graywackes in this railroad cut yielded to the D_2 stress by buckling. Ghosh and Ramberg (1968) have shown that in buckle folding of previously deformed systems, when the intermediate strain of the second deformational field is inclined less than 30° to antecedent fold axis, deformation is accomplished by progressive tightening of the preexisting folds, with reorientation of their axes toward parallelism with intermediate strain axis of the superimposed field. At higher inclinations, polyaxial fabrics are developed. Given the fabric of the diagram, it may be safely concluded, therefore, that B_2 represents the B_1 axis more or less reoriented toward B_2, and lying within 30° of its original orientation, unless it is substantially affected by still later events.

Several lines of evidence, in fact, suggest that β_2 is the best determinable indication of B_2 in this exposure. The most obvious is that it shows good agreement with the regional strike of the South Mountain anticlinorium and the values of B_2 determined at Plainfield and Indian Creek. With a somewhat simpler fabric geometry this argument alone might be compelling, but the incongruence of B_2 with the maximum of measured folds and observed S_2 cleavage requires explanation. In evaluating these anomalies it should be reemphasized that the S_0 girdle generating B_2 reflects the orientation of the largest folds in the most massive graywacke beds, which would be least prone to reorientation. This fact alone might suggest that the lesser folds forming the obvious maximum of the diagram might lie closer to B_2, with B_2 reflecting a partially reoriented structure. However, the distribution of the fold axes and B lineations, systematically spread beyond the 30° circle about B_2, clearly reflects the influence of some later event (D_3). Reorientation in D_3 is clearly not complete; and β_2 is thus, by reason of the size and competence of the structures involved, at least closer than the majority of minor fold axes to the original B_2 position. The incongruence of B_2 and observed S_2 may be influenced by several factors. It was previously suggested that S_2 developed as a discrete surface in those areas where S_1 was unfavorably oriented for reactivation in D_2. Development of discrete S_2 is not noted where S_1 lies close to AC_2 and is congruent with B_2 as the reactivated surface. Inasmuch as zones of unfavorably oriented antecedent fabric are likely to represent zones of strain anomaly, this might be proposed as the explanation of the observed S_2 distribution. Furthermore, as S_2 is commonly observed in incompetent argillaceous rocks, it might be more subject to some reorientation in D_3 than the graywacke folds generating B_2. This possibility is reinforced by the fact that the observed S_2 does tend to be congruent with the reoriented fold maximum. This latter relationship suggests an alternative hypothesis that the surface here designated S_2 was in fact not generated until the final (D_3) reorienting event and is in fact an S_3 surface. This interpretation, however, is not consistent with the conditions at Center Street (Figure 29), where the S_2 is surely the South Mountain cleavage. Furthermore, it will be shown that this surface is not compatible with the style or orientation of D_3 as defined by independent criteria. In any case, it does appear clear that β_2 is a more reliable indication of original D_2 geometry than any conflicting data.

The distribution of observed fold axes and bedding-cleavage intersections (B lineations), which is incongruent with the geometry deduced for D_1 and D_2, has been noted as indicative of a late reorienting event, D_3. These elements share a well-defined maximum plunging 095/36°, with the remaining poles somewhat diffusely scattered along a girdle for which the circle $\overline{AB}_3$ of Figure 27c is the visual best fit. Such great-circle distribution of lineation poles is generated when preexisting lineations are passively transposed in slip folding or simple shear deformation. During such reorientation, movement of preexisting lineations is toward parallelism with the movement (A) direction, with partial reorientation producing great circles passing through A. In the general case there is no reason that this circle must define the plane AB; though it is predictably probable from the strong, statistically homoclinal anisotropy of the antecedent structure. The plane is shown, in fact, to be $\overline{AB}_3$ by independent criteria.

Further inferences about the D_3 event might speculatively be drawn from these data alone, but data from the slickensides on the low-angle faults previously discussed permit a more precise evaluation. Assuming the data are coherent and represent a single event, the generally northwest and southeast plunging slickensides should lie in and define the statistical deformation plane AC, which is normal to the intermediate stress axis B. The scatter of the data is such as to allow considerable variation in a visual estimate for the best fit of AC; but an auxiliary β-type construction yields a single well-defined maximum (β_3 of Figure 27c, 209/31°), the corresponding plane (AC_3) being a unique best fit for coplanarity of the slickensides. This circle passes precisely through the fold axis maximum, which confirms the natural assumption that the late thrusting and fold reorientation are products of the same movement plan, and uniquely identifies the A_3 axis. Constructing the $\overline{BC}_3$ plane perpendicular to this axis yields the C_3 axis (328/30°) by the $\overline{AC}_3$ - BC_3 intersection, and the deformational coordinates are fully specified. The C_3 axis is normal to the mean bedding and foliation in the exposure, which confirms the expectation that the D_3 deformation (apart from discrete thrusting) was accomplished by slip on the antecedent foliation. It is this movement geometry that constrains migration of the antecedent fold axes to the $\overline{AB}_3$ plane.

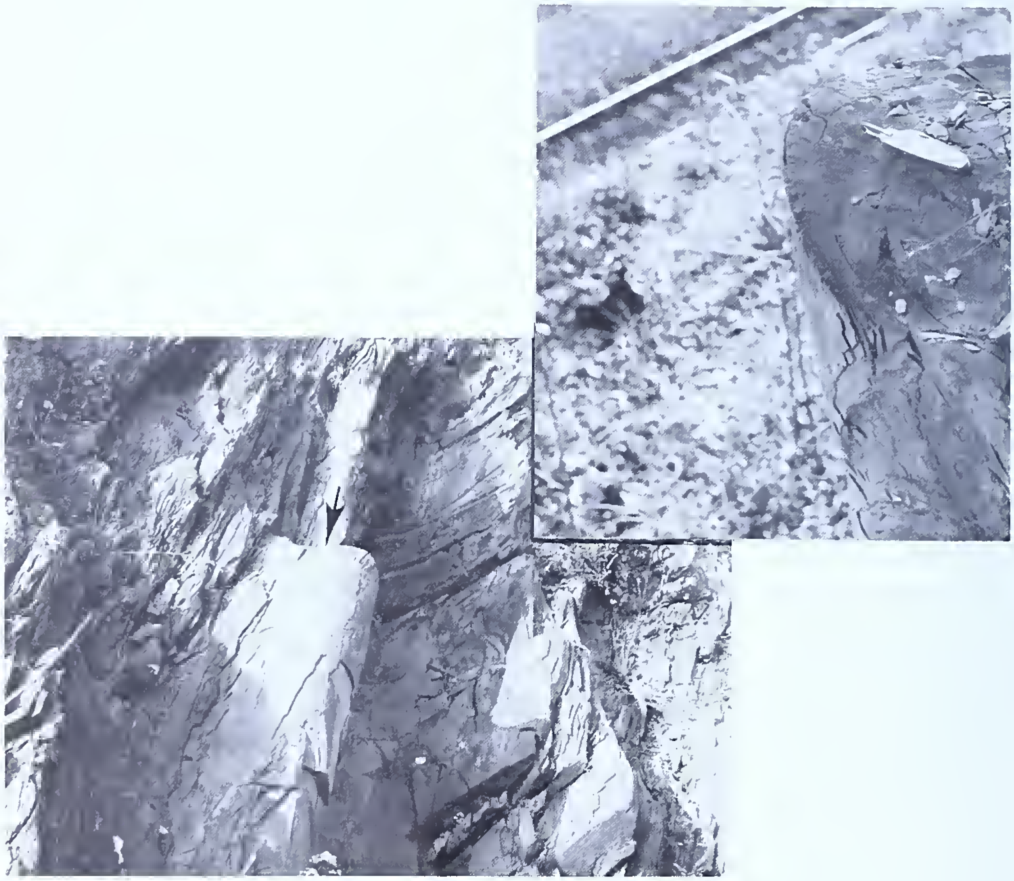


Figure 30. Isoclinal Taconic folds in allochthonous rocks of the Yellow Breeches klippe (see Figure 27c) which have been reoriented so that they now plunge down the dip of the cleavage (B B′ reclined fold). The outcrop surface is vertical; cleavage and folds are steeply inclined from top right to bottom left. Arrow points to prominent reclined fold and location of inset photo, which is downplunge view of fold.

The obvious effect of D_3 in this exposure is to reorient the folds into reclined structures plunging down the dip of the cleavage (Figure 30). Similarly, though even more completely, reoriented folds are characteristic of Cumberland Valley rocks only near the Yellow Breeches thrust. As these occurrences are similar in orientation and relative sequence of structural development, the presumption seems warranted that they are of related origin and that this area is a klippe of the Yellow Breeches thrust sheet.

Comparison of the diagrams for the Plainfield area (Figure 27a) and Indian Creek (Figure 27b) and Figure 27c will show that there does seem to be some progression eastward in development of the D_3 structures. The first clearly shows a simple kinematically congruent pattern. While there is no positive evidence of subsequent deformation in the second diagram alone, there is considerably more dispersion of the data. When this scatter is compared with Figure 26c, considerable similarity is indicated, suggesting that marginal D_3 effects are indeed responsible for the dispersion on Figure 26b. Such increase of intensity can reasonably be related to proximity to the Yellow Breeches thrust and tends to confirm identification of D_3 in the shales with Yellow Breeches thrust development.

APPENDIX 4

PHYSICAL TESTS OF SHALES

Sample 147-C-8

Location: 40°15′47″N/76°58′39″W

Description: Shale, medium-gray, weathers to buff, hard, well-bedded in beds to 8 ft thick, with beds to 1 ft thick of hard siltstone and very fine grained graywacke.

Sampled interval: Composite of shale beds.

Type of material: Shale	Color: Dry: Lt gry Wet: Dk gry	Grind: Mesh: −20
Water of plasticity %: 20.9	Plasticity: Fair	Workability: Fair—fine
% drying shrinkage, plastic basis: 3.5	Dry strength: Poor	Drying properties: Good
Slow-firing test:		L.O.I.: 18.7%
Heating rate: 525°F/hr to 1800°F, then 125°F/hr		pH: 6

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	Apparent sp. gr. SG
1900	7.5YR7/4 Med tan	2.0	4.0	0.5	25.7	1.57	2.64

Temp. F°	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	SG
2000	7.5YR7/4 Med tan	2.0	2.5	0.0	25.3	1.58	2.63
2100	7.5YR8/4 Lt tan	2.5	4.5	0.0	26.7	1.55	2.64
2200	PYROPLASTIC MASS						

Quick-firing test:

Retention time, min: 15		Temperature °F			
		1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	103.0	89.8	69.3	50.5
	Absorption %	19.4	21.4	22.3	31.5

Other tests and comments: $CaCO_3$ very positive. 78.0 micromhos/cm. Pyroplastic mass on 2200°F tile.

Potential uses: Possible use as a nonplastic component in most structural clay products. Probable use as a fair lightweight aggregate.

Sample 147-C-9

Location: 40°16′14″N/76°58′16″W

Description: Shale, medium-gray (N4), considerably weathered to buff, thin-bedded, with 10 to 20 percent thin interbands of siltstone and graywacke.

Sampled interval: Composite from outcrop.

Type of material: Shale
Color: Dry: Lt gry
Wet: Dk gry
Grind: Mesh: −20

Water of plasticity %: 24.3
Plasticity: Fair
Workability: Fair—fine

% drying shrinkage, plastic basis: 3.7
Dry strength: Poor
Drying properties: Good

Slow-firing test:
L.O.I.: 8.7%

Heating rate: 525°F/hr to 1800°F, then 125°F/hr
pH: 7

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	SG
1900	5YR7/6 Buff	1.5	3.0	0.5	22.0	1.64	2.56
2000	5YR7/6 Buff	1.5	3.5	0.5	21.8	1.63	2.54

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	Apparent sp. gr. SG
2100	5YR6/6 Lt orn brn	2.5	3.5	0.5	20.3	1.68	2.55

Quick-firing test:

Retention time, min: 15		Temperature °F			
		1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	116.7	107.3	83.0	57.3
	Absorption %	9.1	9.0	12.4	21.1

Other tests and comments: $CaCO_3$ very positive. 108.0 micromhos/cm. Tile fused to firing tray at 2200°F.

Potential uses: Possible use as a nonplastic component in most structural clay products. Probable use as a fair lightweight aggregate.

Sample 147-C-10

Location: 40°17′20″N/76°59′41″W

Description: Mudstone, red, weathers light yellow buff, thin-bedded, slightly silty, no interbeds of siltstone or sandstone.

Sampled interval: Composite from outcrop.

Type of material: Shale

Color: Dry: Lt tan
Wet: Dk brn

Grind: Mesh: −20

Water of plasticity %: 21.0

Plasticity: Fair

Workability: Good

% drying shrinkage, plastic basis: 4.0

Dry strength: Fair

Drying properties: Good

Slow-firing test:

L.O.I.: 5.4%

Heating rate: 525°F/hr to 1800°F, then 125°F/hr

pH: 6

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	Apparent sp. gr. SG
1900	2.5YR6/8 Med orn brn	2.0	5.5	0.0	15.9	1.82	2.58
2000	5YR5/6 Orn brn	2.0	6.5	1.0	13.8	1.91	2.58
2100	5YR4/6 Lt red brn	4.0	8.0	3.5	11.3	2.00	2.58
2200	2.5YR4/2 Dk brn	7+	9.5	6.5	2.6	2.30	2.45

Quick-firing test:

		Temperature °F			
Retention time, min: 15		1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	132.9	149.8	151.0	134.8
	Absorption %	5.2	3.1	2.1	2.6

Other tests and comments: $CaCO_3$ slightly positive. 44.4 micromhos/cm. No defects on fired tiles.

Potential uses: Probable use as a component in most structural clay products including sewer pipe.

Sample 147-C-11

Location: 40°17′16″N/76°57′40″W

Description: Shale to mudstone, red, weathers light yellow buff, in beds 20 to 40 ft thick, with ½- to 1-m interbeds of siltstone and very fine grained sandstone.

Sampled interval: Composite of shale interbeds.

Type of material: Shale

Color: Dry: Med brn red
Wet: Dk brn red

Grind: Mesh: −20

Water of plasticity %: 26.0

Plasticity: Fair

Workability: Fair—fine

% drying shrinkage, plastic basis: 2.3

Dry strength: Fair

Drying properties: Good

Slow-firing test:

L.O.I.: 1.6%

Heating rate: 525°F/hr to 1800°F, then 125°F/hr

pH: 6.0

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr.	
						BD	SG
1900	5YR6/6 Lt orn brn	2.0	4.5	2.0	14.2	1.92	2.63
2000	5YR5/6 Orn brn	2.5	7.0	4.5	13.2	1.95	2.62
2100	5YR4/6 Lt red brn	6.0	8.0	7.0	9.1	2.11	2.61
2200	5YR4/2 Med brn	7+	11.0	10.0	8.1	2.01	2.26

Quick-firing test:

		Temperature °F			
Retention time, min: 15		1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	136.7	150.4	137.9	122.9
	Absorption %	4.1	2.6	2.1	3.0

Other tests and comments: $CaCO_3$ negative. 57.6 micromhos/cm. Slight warping at 2200°F.

Potential uses: Probable use as a main component in brick and tile.

Sample 147-C-12

Location: 40°16′20″N/76°56′27″W

Description: Shale, medium-gray, weathers buff, hard, well-bedded with beds to 2 in thick of hard siltstone and very fine grained graywacke.

Sampled interval: Composite of shale interbeds.

Type of material: Shale

Color: Dry: Med gry
Wet: Dk gry

Grind: Mesh: −20

Water of plasticity %: 25.1

Plasticity: Fair

Workability: Fair—fine

% drying shrinkage, plastic basis: 4.2

Dry strength: Fair

Drying properties: Good

Slow-firing test:

L.O.I.: 2.2%

Heating rate: 525°F/hr to 1800°F, then 125°F/hr

pH: 6.0

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	SG
1900	5YR7/6 Buff	2.0	5.0	2.0	16.2	1.83	2.61
2000	7.5YR6/6 Dk buff	4.0	5.0	1.0	14.1	1.88	2.55
2100	5YR4/4 Lt red brn	6.0	9.5	5.0	7.8	2.10	2.51

Quick-firing test:

Retention time, min: 15		Temperature °F			
		1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	106.7	73.0	36.8	36.8
	Absorption %	3.7	11.7	49.5	49.4

Other tests and comments: $CaCO_3$ positive. 55.2 micromhos/cm. Tile fused to kiln shelf at 2200°F.

Potential uses: Probable use in brick and tile. Probable use as an excellent lightweight aggregate.

Sample 148-A-9

Location: 40°12′30″N/76°56′18″N

Description: Phyllitic shale, weathered buff to buff olive gray, silty, well-bedded, a few thin interbands to 2 in. thick of very fine grained graded lithic sandstone, cleavage-dominated.

Sampled interval: Composite from outcrop, all weathered materials.

Type of material: Shale
Color: Dry: Lt yellow
Wet: Med yellow
Grind: Mesh: −20

Water of plasticity %: 27.2
Plasticity: Fair
Workability: Fair—fine

% drying shrinkage, plastic basis: 1.1
Dry strength: Poor
Drying properties: Good

Slow-firing test:

Heating rate: 525°F/hr to 1800°F, then 125°F/hr   pH: 5.0

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	SG
1900	7.5YR7/6 Buff	1.0	1.5	0.0	24.3		2.57
2000	7.5YR7/6 Buff	1.0	1.5	0.5	24.6	1.59	2.60
2100	5YR5/6 Orn brn	2.0	3.5	2.5	19.9	1.72	2.61
2200	7.5YR4/2 Dk gry brn	7+	9.0	8.0	7.2	2.14	2.52

Quick-firing test:

		Temperature °F			
Retention time, min: 15		1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	116.7	106.1	117.9	116.7
	Absorption %	17.1	15.0	12.7	9.6

Other tests and comments: $CaCO_3$ negative. 60.0 micromhos/cm. No defects on fired tiles. Suggest the addition of a more plastic clay to increase dry strength.

Potential uses: Probable use as a component in most structural clay products including sewer pipe.

Sample 148-A-10

Location: 40°10′28″N/76°59′26″W

Description: Phyllitic shale, light-olive-gray-green to green-gray, weathers in shades of buff and orange, slightly silty, hard, well-bedded, isoclinally folded.

Sampled interval: Composite from outcrop.

Type of material: Shale
Color: Dry: Lt grn
Wet: Med grn
Grind: Mesh: −20

Water of plasticity %: 23.3
Plasticity: Fair
Workability: Fair—fine

% drying shrinkage, plastic basis: 3.1

Dry strength: Poor

Drying properties: Good

Slow-firing test:

Heating rate: 525°F/hr to 1800°F, then 125°F/hr

L.O.I.: 2.8%

pH: 6

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	Apparent sp. gr. SG
1900	7.5YR7/8 Lt orn brn	1.5	3.0	0.0	24.4	1.62	2.68
2000	7.5YR7/6 Buff	1.5	5.5	2.5	21.2	1.69	2.64
2100	5YR5/6 Orn brn	3.0	10.0	7.0	12.7	1.94	2.58
2200	5YR3/2 Dk brn	7+	15.0	12.0	0.8	2.36	2.40

Quick-firing test:

		Temperature °F			
Retention time, min: 15		1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	121.1	129.8	117.3	90.5
	Absorption %	9.3	4.3	4.8	5.3

Other tests and comments: $CaCO_3$ negative. 19.2 micromhos/cm. No defects on fired tiles. Suggest the addition of a more plastic clay to increase dry strength.

Potential uses: Probable use in brick and tile.

Sample 148-A-11

Location: 40°11′30″N/76°58′42″W

Description: Phyllitic shale, medium-gray (N3 to N4), weathers olive drab, slightly silty, poorly bedded.

Sampled interval: Composite from outcrop.

Type of material: Shale

Color: Dry: Lt grn
Wet: Dk grn

Grind: Mesh: –20

Water of plasticity %: 21.7

Plasticity: Fair

Workability: Fair–fine

% drying shrinkage, plastic basis: 2.2

Dry strength: Poor

Drying properties: Good

Slow-firing test:

Heating rate: 525°F/hr to 1800°F, then 125°F/hr

L.O.I.: 3.5%

pH: 6

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	Apparent sp. gr. SG
1900	7.5YR7/8 Lt orn brn	1.5	2.5	0.0	19.3	1.74	2.63
2000	7.5YR7/8 Lt orn brn	3.0	2.5	0.5	17.7	1.79	2.63
2100	5YR5/6 Orn brn	6.0	5.0	3.0	10.9	2.02	2.58
2200	5YR3/2 Dk brn	7+	9.5	7.0	7.2	1.75	2.00

Quick-firing test:

Retention time, min: 15		Temperature °F 1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	134.8	134.2	135.4	68.0
	Absorption %	4.6	3.6	4.6	15.8

Other tests and comments: $CaCO_3$ negative. 60.0 micromhos/cm. Warping at 2200°F.

Potential uses: Possible use as a nonplastic component in most structural clay products.

Sample 148-A-12

Location: 40°12′43″N/76°54′22″W

Description: Phyllitic shale, medium-gray (N4), with 3- to 6-in. beds of siltstone and graywacke, isoclinally folded.

Sampled interval: Composite from outcrop.

Type of material: Shale

Color: Dry: Lt gry
Wet: Charcoal gry

Grind: Mesh: −20

Water of plasticity %: 17.6

Plasticity: Fair

Workability: Fair–fine

% drying shrinkage, plastic basis: 1.2

Dry strength: Poor

Drying properties: Good

Slow-firing test:

L.O.I.: 4.3%

Heating rate: 525°F/hr to 1800°F, then 125°F/hr

pH: 5

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	Apparent sp. gr. SG
1900	7.5YR6/6 Dk buff	1.5	1.0	0.0	19.7	1.73	2.62

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	Apparent sp. gr. SG
2000	5YR6/6 Lt orn brn	3.0	1.0	0.0	18.0	1.77	2.60
2100	5YR5/6 Orn brn	4.0	3.5	2.0	13.8	1.92	2.60
2200	5YR3/1 Dk gry	7+	5.0	4.0	10.3	1.75	2.14

Quick-firing test:

Retention time, min: 15		Temperature °F 1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	121.1	123.6	101.1	77.5
	Absorption %	6.7	7.1	11.3	15.7

Other tests and comments: $CaCO_3$ positive. 13.2 micromhos/cm. Slight warping at 2200°F.

Potential uses: Possible use as a nonplastic component in most structural clay products. Possible use as a poor lightweight aggregate.

Sample 148-A-13

Location: 40°13′05″N/76°52′58″W

Description: Phyllitic shale, medium-gray (N4), weathers buff, in beds 1 to 2 ft thick, with 1- to 2-in. interbeds of siltstone and very fine grained graywacke.

Sampled interval: Composite from outcrop but mostly shale.

Type of material: Shale

Color: Dry: Lt blue gry
Wet: Dk blue gry

Grind: Mesh: −20

Water of plasticity %: 24.2

Plasticity: Fair

Workability: Fair–fine

% drying shrinkage, plastic basis: 2.5

Dry strength: Poor

Drying properties: Good

Slow-firing test:

L.O.I.: 5.9%

Heating rate: 525°F/hr to 1800°F, then 125°F/hr

pH: 7

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr. BD	Apparent sp. gr. SG
1900	7.5YR7/6 Buff	1.0	2.5	0.0	26.0	1.55	2.61

Temp. °F	Color	Moh's hardness	Total shrinkage: % of plastic length	Firing shrinkage: % of plastic length	Absorption %	Apparent sp. gr.	
						BD	SG
2000	7.5YR6/6 Dk buff	1.0	2.5	0.0	24.1	1.60	2.61
2100	5YR5/4 Med brn	6.0	3.5	1.0	17.0	1.77	2.53
2200	5YR3/1 Dk gry	7+	9.0	6.5	10.0	1.79	2.19

Quick-firing test:

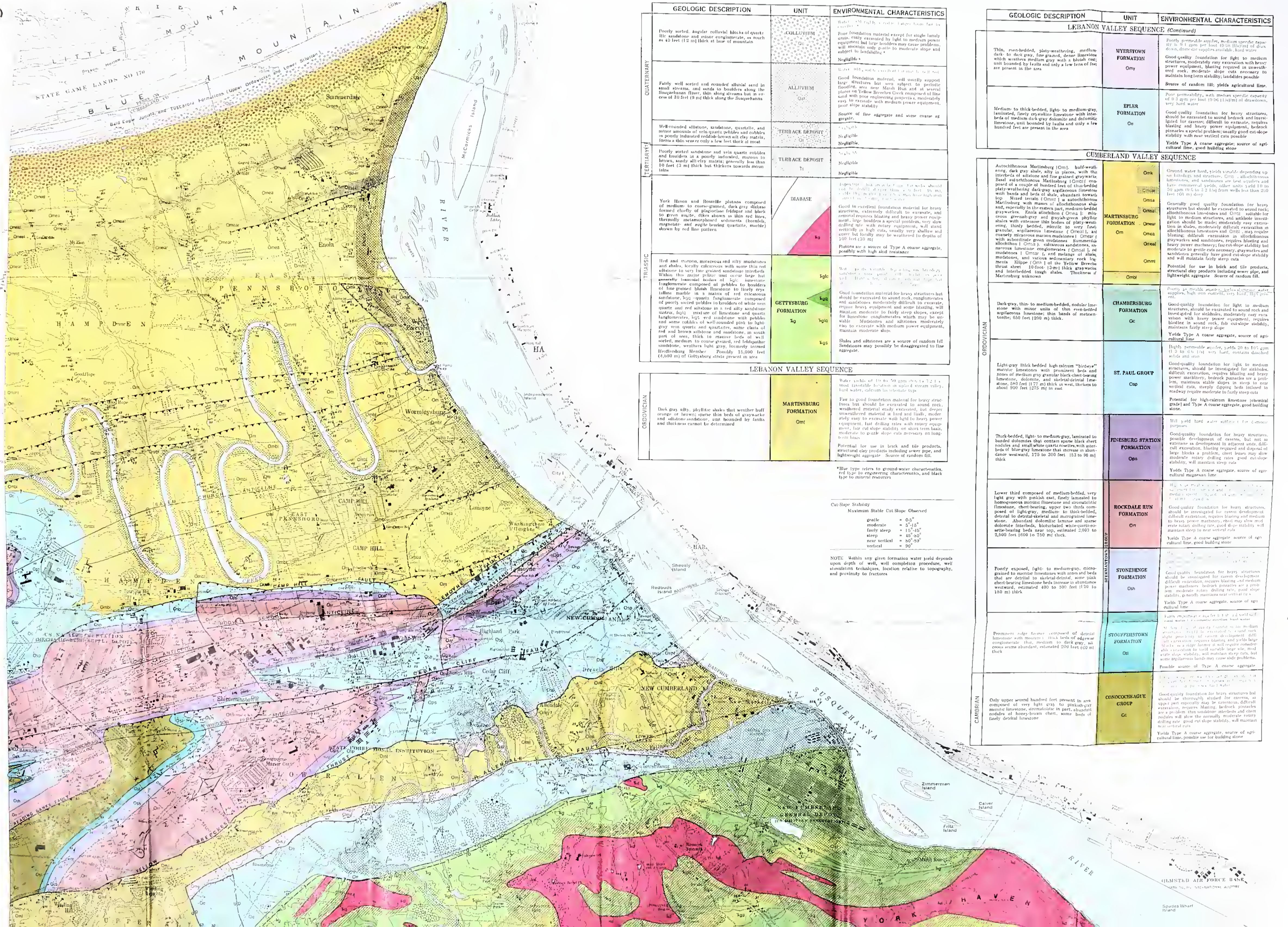
Retention time, min: 15		Temperature °F			
		1900	2000	2100	2200
Particle size through 525 on 4	Weight lb/cu ft	114.8	94.8	75.5	51.2
	Absorption %	3.3	4.4	13.2	35.2

Other tests and comments: $CaCO_3$ positive. 24.0 micromhos/cm. Slight warping at 2200°F.

Potential uses: Possible use as a nonplastic component in most structural clay products. Possible use as a good lightweight aggregate.

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES



EXPLANATION

	GEOLOGIC DESCRIPTION	UNIT	ENVIRONMENTAL CHARACTERISTICS
QUATERNARY	Poorly sorted, angular colluvial blocks of quartzite sandstone and minor conglomerate, as much as 40 feet (12 m) thick at base of mountain	COLLUVIUM Qc	Water yields highly variable, ranges from fair to excellent.* Poor foundation material except for single family units, easily excavated by light to medium power equipment but large boulders may cause problems, will maintain only gentle to moderate slope and subject to landsliding.* Negligible.*
	Fairly well sorted and rounded alluvial sand in small streams, and sands to boulders along the Susquehanna River, thin along streams but in excess of 30 feet (9 m) thick along the Susquehanna	ALLUVIUM Qal	Water yields good to excellent but may be [illegible] Good foundation material, will usually support large structures but area subject to periodic flooding, area near Marsh Run and at several places on Yellow Breeches Creek composed of fine sand with poor engineering properties, moderately easy to excavate with medium power equipment, poor slope stability Source of fine aggregate and some coarse aggregate.
	Well-rounded siltstone, sandstone, quartzite, and minor amounts of vein quartz pebbles and cobbles in poorly indurated reddish-brown silt clay matrix, forms a thin veneer only a few feet thick at most	TERRACE DEPOSIT Qt	Negligible Negligible Negligible.
TERTIARY(?)	Poorly sorted sandstone and vein quartz cobbles and boulders in a poorly indurated, maroon to brown, sandy silt-clay matrix; generally less than 10 feet (3 m) thick but thickens towards mountains	TERRACE DEPOSIT Tt	Negligible Negligible Negligible
TRIASSIC	York Haven and Rossville plutons composed of medium- to coarse-grained, dark gray diabase formed chiefly of plagioclase feldspar and black to green augite, dikes shown as thin red lines, thermally metamorphosed sediments (hornfels, magnetite- and augite-bearing quartzite, marble) shown by red line pattern	DIABASE Ŧd	[illegible] wells should not be drilled deeper than [illegible] feet ([illegible] m), [illegible] may have high iron content [illegible] hard water Good to excellent foundation material for heavy structures, extremely difficult to excavate, and removal requires blasting and heavy power equipment, large boulders a special problem, very slow drilling rate with rotary equipment, will stand vertically in high cuts, usually very shallow soil cover but locally may be weathered to depths of 100 feet (30 m) Plutons are a source of Type A coarse aggregate, possibly with high skid resistance
	Red and maroon, micaceous and silty mudstones and shales, locally calcareous with some thin red siltstone to very fine grained sandstone interbeds. Within this major pelitic unit occur large but generally lensoidal bodies of Ŧglc -limestone fanglomerate composed of pebbles to boulders of fine grained bluish limestone to finely crystalline marble in a matrix of red calcareous sandstone, Ŧgq -quartz fanglomerate composed of poorly sorted pebbles to boulders of white vein quartz and red siltstone in a red silty sandstone matrix, Ŧglq -mixture of limestone and quartz fanglomerates, Ŧgs -red sandstone with pebbles and some cobbles of well-rounded pink to light-gray vein quartz and quartzites, some clasts of red and brown siltstone and sandstone, in south part of area, thick to massive beds of well sorted, medium- to coarse-grained, red feldspathic sandstone, weathers light gray, formerly termed Heidlersburg Member. Possibly 15,000 feet (4,600 m) of Gettysburg strata present in area	GETTYSBURG FORMATION Ŧg Ŧglc Ŧgq Ŧglq Ŧgs	Water yields variable depending on lithology, sandstones have good [illegible] Hard water [illegible] Good foundation material for heavy structures but should be excavated to sound rock, conglomerates and sandstones moderately difficult to excavate, require heavy equipment and some blasting, will maintain moderate to fairly steep slopes, except for limestone conglomerates which may be unstable. Mudstones and siltstones moderately easy to excavate with medium power equipment, maintain moderate slope Shales and siltstones are a source of random fill. Sandstones may possibly be disaggregated to fine aggregate.

LEBANON VALLEY SEQUENCE

	GEOLOGIC DESCRIPTION	UNIT	ENVIRONMENTAL CHARACTERISTICS
ORDOVICIAN	Dark gray silty, phyllitic shales that weather buff orange or brown; sparse thin beds of graywacke and siltstone-sandstone, unit bounded by faults and thickness cannot be determined	MARTINSBURG FORMATION Omt	Water yields of 10 to 50 gpm (0.6 to 3.2 l/s), most favorable location in upland stream valley, hard water, calcium bicarbonate type Fair to good foundation material for heavy structures but should be excavated to sound rock, weathered material easily excavated, but deeper unweathered material is hard and fissile, moderately easy to excavate with light to heavy power equipment, fast drilling rates with rotary equipment, fair cut slope stability on short term basis, moderate to gentle slope cuts necessary on long-term basis Potential for use in brick and tile products, structural clay products including sewer pipe, and lightweight aggregate. Source of random fill.

*Blue type refers to ground-water characteristics, red type to engineering characteristics, and black type to mineral resources

Cut-Slope Stability
Maximum Stable Cut Slope Observed

gentle	= 0-5°
moderate	= 5°-15°
fairly steep	= 15°-45°
steep	= 45°-80°
near vertical	= 80°-89°
vertical	= 90°

NOTE: Within any given formation water yield depends upon depth of well, well completion procedure, well stimulation techniques, location relative to topography, and proximity to fractures

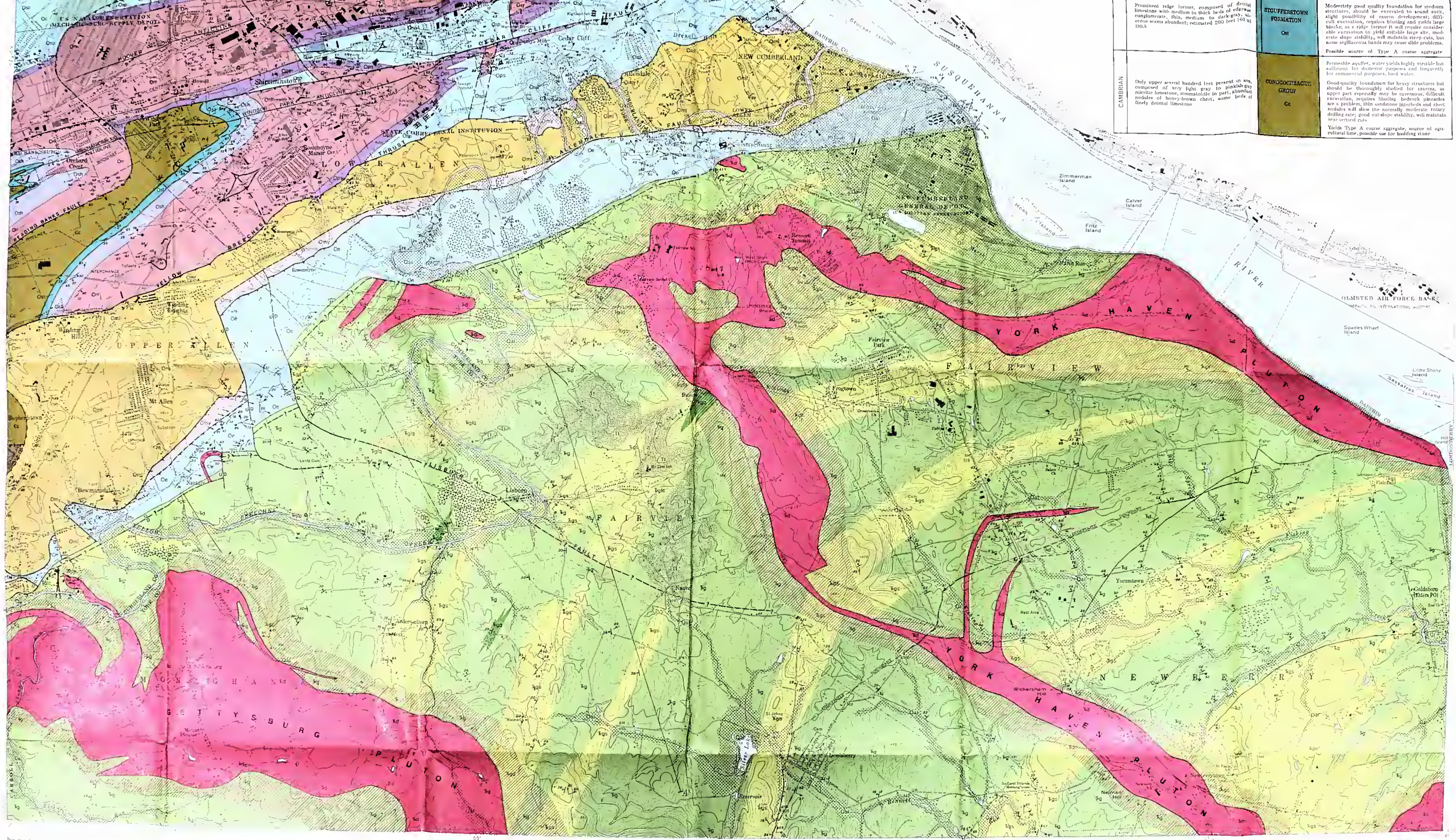
LEBANON VALLEY SEQUENCE *(Continued)*

	GEOLOGIC DESCRIPTION	UNIT	ENVIRONMENTAL CHARACTERISTICS
	Thin, even-bedded, platy-weathering, medium-dark- to dark gray, fine grained, dense limestone which weathers medium gray with a bluish cast; unit bounded by faults and only a few tens of feet are present in the area	MYERSTOWN FORMATION Omy	Poorly permeable aquifer, medium specific capacity is 0.1 gpm per foot (0.08 (l/s)/m) of drawdown, domestic supplies available, hard water Good quality foundation for light to medium structures, moderately easy excavation with heavy power equipment, blasting required in unweathered rock, moderate slope cuts necessary to maintain long term stability; landslides possible Source of random fill; yields agricultural lime.
	Medium- to thick-bedded, light- to medium-gray, laminated, finely crystalline limestone with interbeds of medium dark-gray dolomite and dolomitic limestone, unit bounded by faults and only a few hundred feet are present in the area	EPLER FORMATION Oe	Poor permeability, with median specific capacity of 0.3 gpm per foot (0.06 (l/s)/m) of drawdown, very hard water Good quality foundation for heavy structures, should be excavated to sound bedrock and investigated for caverns; difficult to excavate, requires blasting and heavy power equipment, bedrock pinnacles a special problem; usually good cut-slope stability with near vertical cuts possible Yields Type A coarse aggregate; source of agricultural lime, good building stone

CUMBERLAND VALLEY SEQUENCE

	GEOLOGIC DESCRIPTION	UNIT	ENVIRONMENTAL CHARACTERISTICS
ORDOVICIAN	Autochthonous Martinsburg (Om), buff-weathering, dark gray shale, silty in places, with thin interbeds of siltstone and fine grained graywacke. Basal autochthonous Martinsburg (Ombl) composed of a couple of hundred feet of thin-bedded platy-weathering dark-gray argillaceous limestone with bands and beds of shale, abundant towards top. Mixed terrain (Omml) is autochthonous Martinsburg with masses of allochthonous shale and, especially in the eastern part, medium-bedded graywackes. Enola allochthon (Omea): micaceous greenish-gray and grayish-green phyllitic shales with extensive thin bodies of platy-weathering, thinly bedded, micritic to very finely granular, argillaceous limestone (Omeal), and coarsely micaceous maroon mudstones (Omear) with subordinate green mudstones. Summerdale allochthon (Omsa), calcareous sandstones, arenaceous limestone conglomerates (Omsal), red mudstones (Omsar), and melange of shale, mudstones, and various sedimentary rock fragments. Klippe (Omk) of the Yellow Breeches thrust sheet: 10-foot- (3-m-) thick graywacke and interbedded tough shales. Thickness of Martinsburg unknown	MARTINSBURG FORMATION Om Omk Omsar Omsa Omsal Omear Omea Omeal Omml Ombl	Ground water hard, yields variable depending upon lithology and structure, Omb , allochthonous limestones, and sandstones are best aquifers and have commercial yields, other units yield 10 to 50 gpm (0.6 to 3.2 l/s) from wells less than 200 feet (60 m) deep Generally good quality foundation for heavy structures but should be excavated to sound rock; allochthonous limestones and Ombl suitable for light to medium structures, and sinkhole investigation should be made; moderately easy excavation in shales, moderately difficult excavation in allochthonous limestones and Ombl, may require blasting; difficult excavation in allochthonous graywackes and sandstones, requires blasting and heavy power machinery; fair cut-slope stability but moderate to gentle cuts necessary, graywackes and sandstones generally have good cut-slope stability and will maintain fairly steep cuts Potential for use in brick and tile products, structural clay products including sewer pipe, and lightweight aggregate. Source of random fill.
	Dark-gray, thin- to medium-bedded, nodular limestone with minor units of thin even-bedded argillaceous limestone; thin bands of metabentonite; 650 feet (200 m) thick.	CHAMBERSBURG FORMATION Oc	Poorly permeable aquifer, yields domestic water supplies, high iron content, very hard, H_2S present. Good-quality foundation for light to medium structures, should be excavated to sound rock and investigated for sinkholes, moderately easy excavation with heavy power equipment, requires blasting in sound rock, fair cut-slope stability, maintains fairly steep slope Yields Type A coarse aggregate, source of agricultural lime
	Light-gray thick bedded high calcium "birdseye" micritic limestones with prominent beds and zones of medium gray granular black-chert-bearing limestone, dolomite, and skeletal-detrital limestone, 580 feet (177 m) thick in west, thickens to about 900 feet (275 m) in east	ST. PAUL GROUP Osp	Highly permeable aquifer, yields 20 to 105 gpm (1.3 to 6.6 l/s), very hard, contains dissolved solids and iron Good-quality foundation for light to medium structures, should be investigated for sinkholes, difficult excavation, requires blasting and heavy power machinery, bedrock pinnacles are a problem, maintains stable slopes in steep to near vertical cuts, steeply dipping beds inclined to roadway require moderate to fairly steep cuts Potential for high-calcium limestone (chemical grade) and Type A coarse aggregate, good building stone.
	Thick-bedded, light- to medium-gray, laminated to banded dolomites that contain sparse black chert nodules and small white quartz rosettes, with interbeds of blue-gray limestone that increase in abundance westward, 175 to 300 feet (53 to 90 m) thick	PINESBURG STATION FORMATION Ops	Will yield hard water sufficient for domestic purposes Good-quality foundation for heavy structures, possible development of caverns, but not as extensive as development in adjacent units, difficult excavation, blasting required and disposal of large blocks a problem, chert lenses may slow moderate rotary drilling rates, good cut-slope stability, will maintain steep cuts Yields Type A coarse aggregate, source of agricultural magnesian lime
	Lower third composed of medium-bedded, very light gray with pinkish cast, finely laminated to homogeneous micritic limestone and stromatolitic limestone, chert-bearing, upper two thirds composed of light-gray, medium- to thick-bedded, detrital to detrital-skeletal and micrograined limestone. Abundant dolomitic laminae and sparse dolomite interbeds, bioturbated white-quartz-rosette-bearing beds near top, estimated 2,000 to 2,500 feet (600 to 750 m) thick.	BEEKMANTOWN GROUP ROCKDALE RUN FORMATION Orr	[illegible] Good quality foundation for heavy structures, should be investigated for cavern development, difficult excavation, requires blasting and medium to heavy power machinery, chert may slow moderate rotary drilling rate, good slope stability, will maintain steep to near vertical cuts Yields Type A coarse aggregate, source of agricultural lime, good building stone
	Poorly exposed, light- to medium-gray, micrograined to micritic limestones with zones and beds that are detrital to skeletal-detrital, some pink chert-bearing limestone beds increase in abundance westward, estimated 400 to 500 feet (120 to 150 m) thick	STONEHENGE FORMATION Osh	[illegible] Good quality foundation for heavy structures, should be investigated for cavern development, difficult excavation, requires blasting and medium power machinery, bedrock pinnacles are a problem, moderate rotary drilling rate, good slope stability, generally maintains near vertical cuts Yields Type A coarse aggregate, source of agricultural lime
	Prominent ridge former, composed of detrital limestone with medium- to thick beds of edgewise conglomerate, thin, medium- to dark gray, argillaceous seams abundant, estimated 200 feet (60 m) thick	STOUFFERSTOWN FORMATION Ost	Fairly impermeable aquifer but will yield sufficient water for domestic supplies, hard water Moderately good quality foundation for medium structures, should be excavated to sound rock, slight possibility of cavern development, difficult excavation, requires blasting and yields large blocks; as a ridge former it will require considerable excavation to yield suitable large site, moderate slope stability, will maintain steep cuts, but some argillaceous bands may cause slide problems. Possible source of Type A coarse aggregate
CAMBRIAN	Only upper several hundred feet present in area composed of very light gray to pinkish-gray micritic limestone, stromatolitic in part, abundant nodules of honey-brown chert, some beds of finely detrital limestone	CONOCOCHEAGUE GROUP Cc	[illegible] hard water Good quality foundation for heavy structures but should be thoroughly studied for caverns, as upper part especially may be cavernous, difficult excavation, requires blasting, bedrock pinnacles are a problem, thin sandstone interbeds and chert nodules will slow the normally moderate rotary drilling rate, good cut slope stability, will maintain near vertical cuts Yields Type A coarse aggregate, source of agricultural lime, possible use for building stone

	Prominent ridge former, composed of detrital limestone with medium to thick beds of edgewise conglomerate, thin, medium to dark-gray, siliceous seams abundant; estimated 200 feet (60 m) thick	**STOUFFERSTOWN FORMATION** Ost	Moderately good quality foundation for medium structures, should be excavated to sound rock, slight possibility of cavern development; difficult excavation, requires blasting and yields large blocks; as a ridge former it will require considerable excavation to yield suitable large site, moderate slope stability, will maintain steep cuts, but some argillaceous bands may cause slide problems. Possible source of Type A coarse aggregate
CAMBRIAN	Only upper several hundred feet present in area, composed of very light gray to pinkish-gray micritic limestone, stromatolitic in part, abundant nodules of honey-brown chert, some beds of finely detrital limestone	**CONOCOCHEAGUE GROUP** Cc	Permeable aquifer, water yields highly variable but sufficient for domestic purposes and frequently for commercial purposes, hard water. Good-quality foundation for heavy structures but should be thoroughly studied for caverns, as upper part especially may be cavernous, difficult excavation, requires blasting bedrock pinnacles are a problem, thin sandstone interbeds and chert nodules will slow the normally moderate rotary drilling rate; good cut-slope stability, will maintain near vertical cuts Yields Type A coarse aggregate, source of agricultural lime, possible use for building stone



Base map from U. S. Geological Survey, Harrisburg West, Lemoyne and Steelton 7½-minute quadrangles

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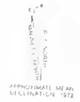
Geology based upon field mapping during 1970-73

Albert E. VanOlden, Cartographer

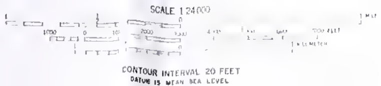


GEOLOGIC MAP OF THE HARRISBURG WEST AREA, CUMBERLAND AND YORK COUNTIES, PENNSYLVANIA

BY

SAMUEL I. ROOT

1977



SYMBOLS

Contact

Dashed where approximately located, dotted where inferred

Steep (reverse) Low angle

Thrust fault

Sawteeth on upper plate. Dashed where approximately located, dotted where concealed

High angle fault

U, upthrown side; D, downthrown side. Dashed where approximately located, dotted where concealed

Facing direction known

Inclined

Vertical

Facing direction unknown

Inclined

Approximate

First cleavage (S_1) Second cleavage (S_2) Third cleavage (S_3)

Strike and dip of cleavage

Note: Includes flow cleavage in carbonate rocks and foliation in shales, which may have layering reoriented into the foliation

Anticlinal Synclinal

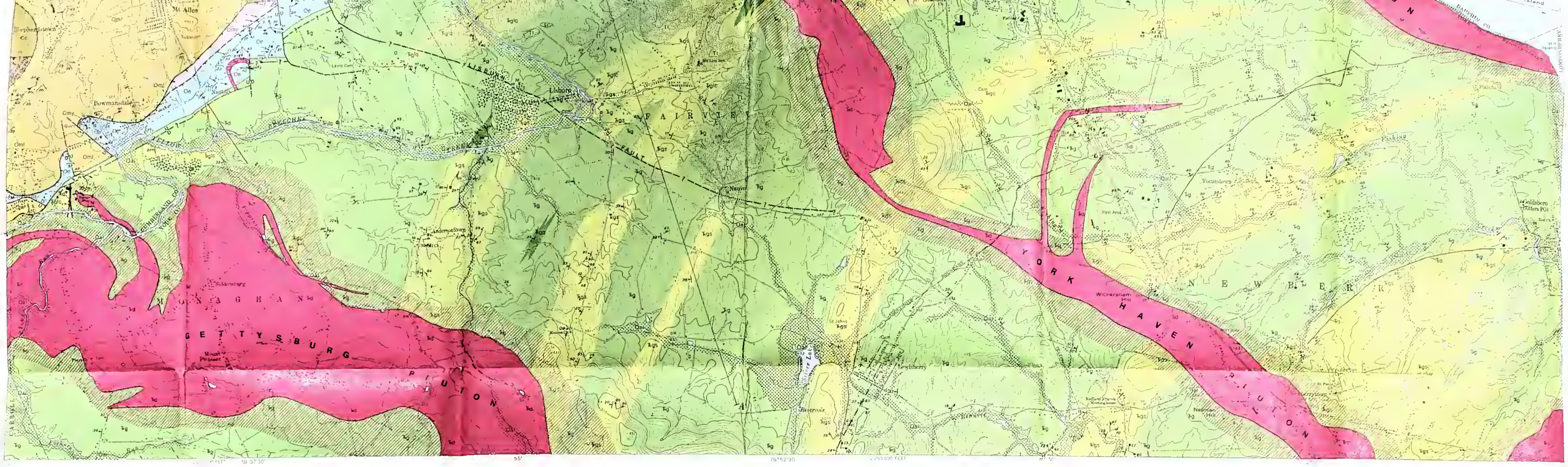
Plunge of minor fold axis

Plunge of axis in closely folded strata

Plunge of overturned minor fold (either antiformal or synformal) and dip of limbs

Anticlinal Synclinal

Plunge of overturned major or minor fold axis and dip of limbs



Base map from U. S. Geological Survey Harrisburg West, Lemoyne, and Steelton 7½-minute quadrangles

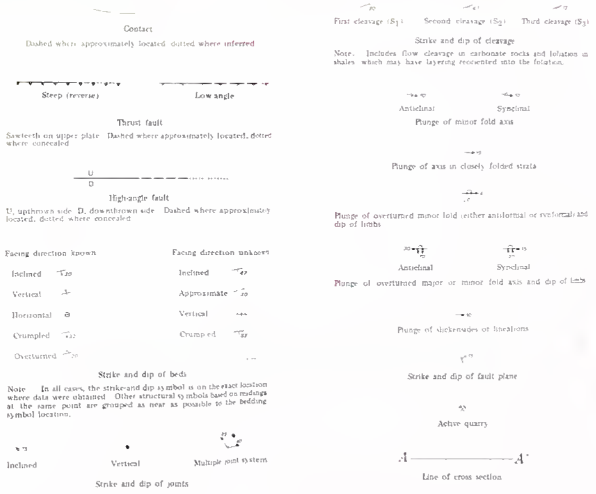
Copyright 1977 by Commonwealth of Pennsylvania

Geology based upon field mapping during 1970
Albert E. VanOlden, Cartographer

GEOLOGIC MAP OF THE HARRISBURG WEST AREA, CUMBERLAND AND YORK COUNTIES, PENNSYLVANIA

BY
SAMUEL I. ROOT
1977

SYMBOLS



Contact
Dashed where approximately located, dotted where inferred

Steep (reverse)
Low angle

Thrust fault
Sawteeth on upper plate. Dashed where approximately located, dotted where concealed

U
D

High-angle fault
U, upthrown side; D, downthrown side. Dashed where approximately located, dotted where concealed

Facing direction known
Inclined
Vertical
Horizontal
Crumpled
Overturned

Facing direction unknown
Inclined
Approximate
Vertical
Crumpled

Strike and dip of beds

Note. In all cases, the strike-and dip symbol is on the exact location where data were obtained. Other structural symbols based on readings at the same point are grouped as near as possible to the bedding symbol location.

Inclined
Vertical
Multiple joint system

Strike and dip of joints

First cleavage (S₁)
Second cleavage (S₂)
Third cleavage (S₃)

Strike and dip of cleavage

Note. Includes flow cleavage in carbonate rocks and foliation in shales which may have layering reoriented into the foliation.

Anticlinal
Synclinal
Plunge of minor fold axis

Plunge of axis in closely folded strata

Plunge of overturned minor fold (either antiformal or synformal) and dip of limbs

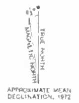
Anticlinal
Synclinal
Plunge of overturned major or minor fold axis and dip of limbs

Plunge of slickensides or lineations

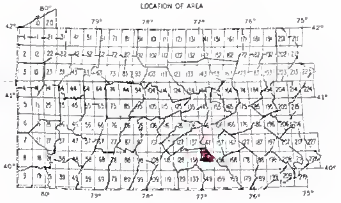
Strike and dip of fault plane

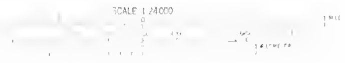
Active quarry

A ——— A′
Line of cross section



APPROXIMATE MEAN DECLINATION, 1972

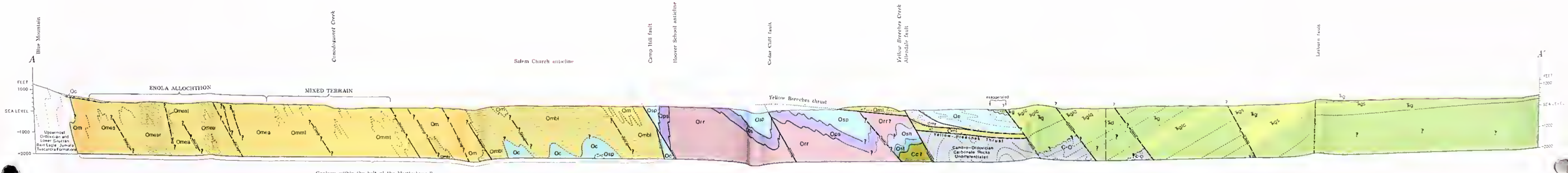



SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

CROSS SECTION

(Horizontal scale same as map scale; no vertical exaggeration)



Geology within the belt of the Martinsburg Formation is extremely diagrammatic